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(54) **METHOD AND SYSTEM FOR DETECTING KNOWN MEASURABLE OBJECT FEATURES**

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(51) **Int. Cl.**
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| G06K 9/00 | (2006.01) |
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CPC .............. *G06T 11/60* (2013.01); *G01B 11/002* (2013.01); *G01B 21/04* (2013.01); *G06K 9/00671* (2013.01); *H04N 5/372* (2013.01); *H04N 5/374* (2013.01); *G06T 2207/10012* (2013.01)

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See application file for complete search history.

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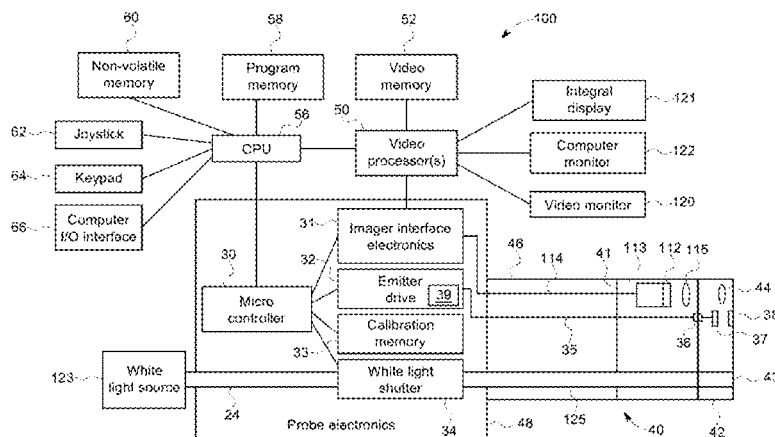| | | | |
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(57) **ABSTRACT**

A method and system for detecting a known measurable object feature using a video inspection system. The method and system displays an image of a viewed object and detects a known measurable object feature on the viewed object. The method and system then displays a set of available measurement types including a measurement type associated with the detected known measurable object feature and/or automatically positions a plurality of measurement markers on the displayed image based on the measurement type associated with the detected known measurable object feature.
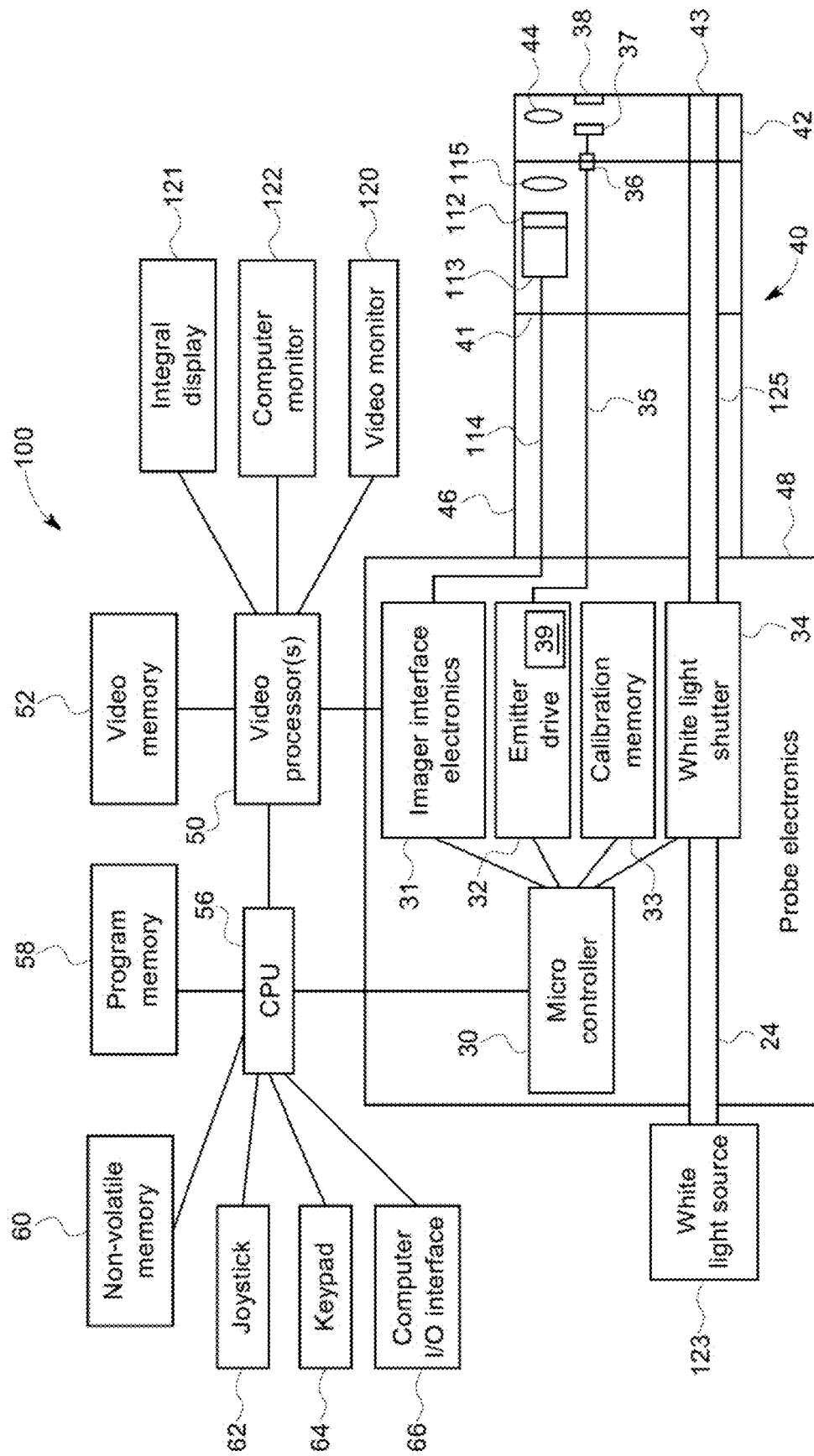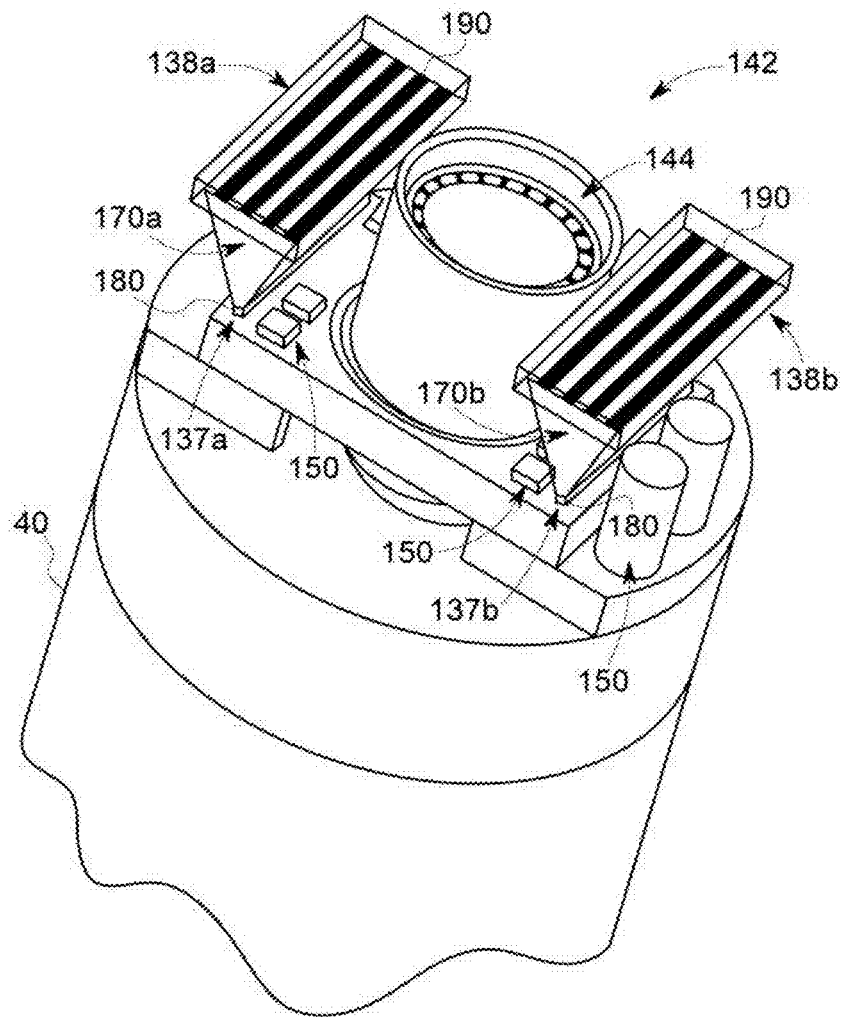
**16 Claims, 15 Drawing Sheets**

FIG. 1

FIG. 2

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                    ( Start )
                        │
                        ▼
  310 ─       ┌──────────────┐   315 ─    ┌──────────────┐   319 ─    ┌──────────────┐
             │    Detect     │──────────▶│  Identify tip │──────────▶│   Retrieve    │
             │  attachment   │           │              │           │ calibration data│
             └──────────────┘           └──────────────┘           └──────────────┘
                    │
                    ▼
  320 ─       ┌──────────────┐   325 ─    ┌──────────────┐
             │  Prompt user  │──────────▶│ Present motion│
             │              │           │ image to guide │
             └──────────────┘           │     user       │
                    │                   └──────────────┘
                    ▼
  330 ─       ┌──────────────┐
             │   Capture     │
             │   images      │
             └──────────────┘
                    │
                    ▼
  340 ─       ┌──────────────┐  359 ─    ┌──────────────┐  360 ─    ┌──────────────┐
             │  Determine    │          │  Determine    │─────────▶│  Determine    │
             │ coordinates   │          │  accuracy     │          │  accuracy     │
             └──────────────┘          │   result      │          │   value       │
                    │                  └──────────────┘          └──────────────┘
                    ▼                        │                          │
  350 ─       ┌──────────────┐               │                          ▼
             │   Measure     │               │            370 ─    ┌──────────────┐
             │  geometric    │               │                    │    Check      │
             │ characteristic │              │                    │  accuracy     │
             └──────────────┘               │                    └──────────────┘
                    │                        │                          │
                    └────────────────┐       ▼                          │
                                     │  380 ─┌──────────────┐  390 ─    ┌──────────────┐
                                     └──────▶│   Provide     │─────────▶│ Activate LED  │
                                            │  indication   │          │ and capture   │
                                            └──────────────┘          │    image      │
                                                                      └──────────────┘
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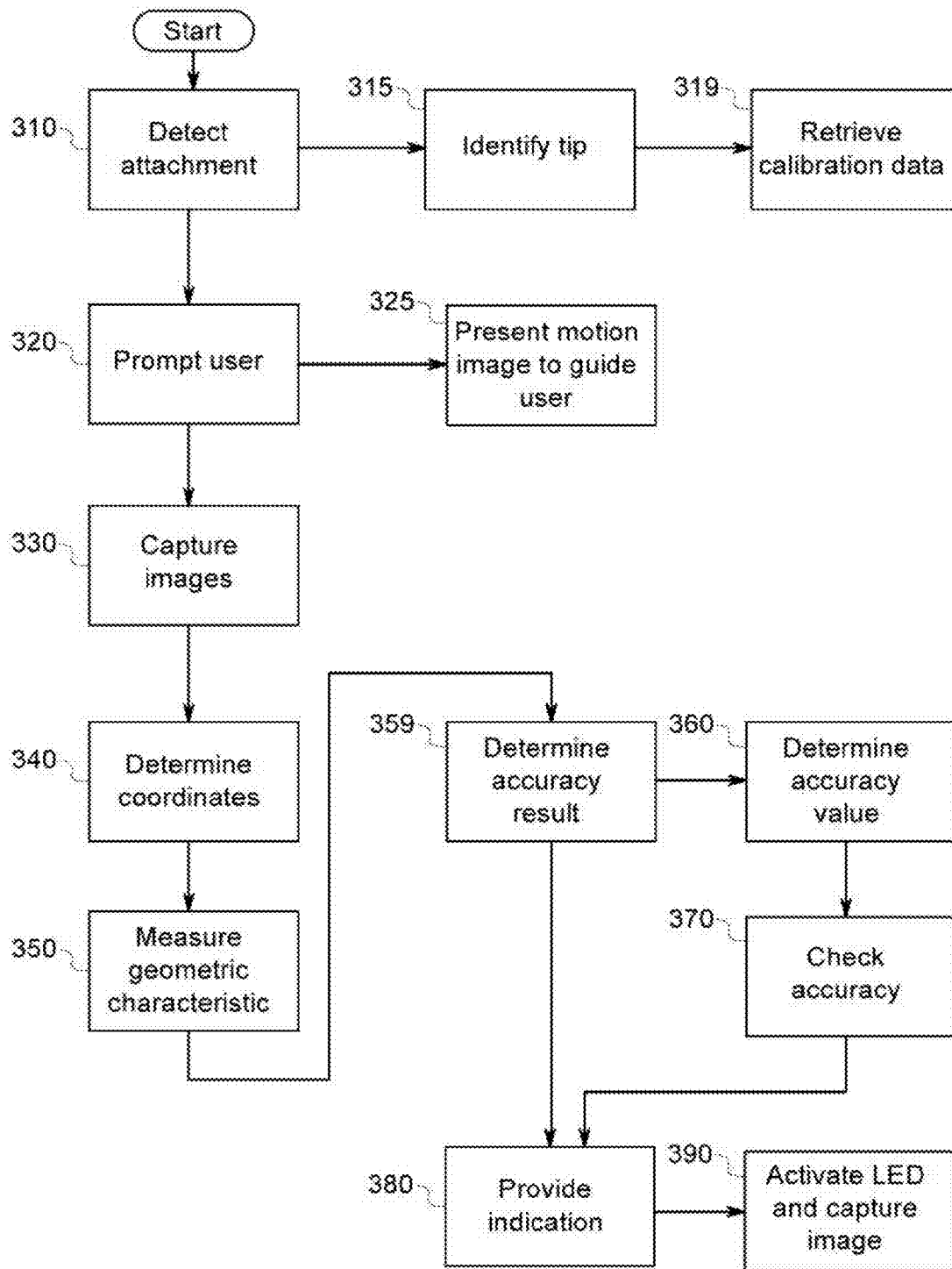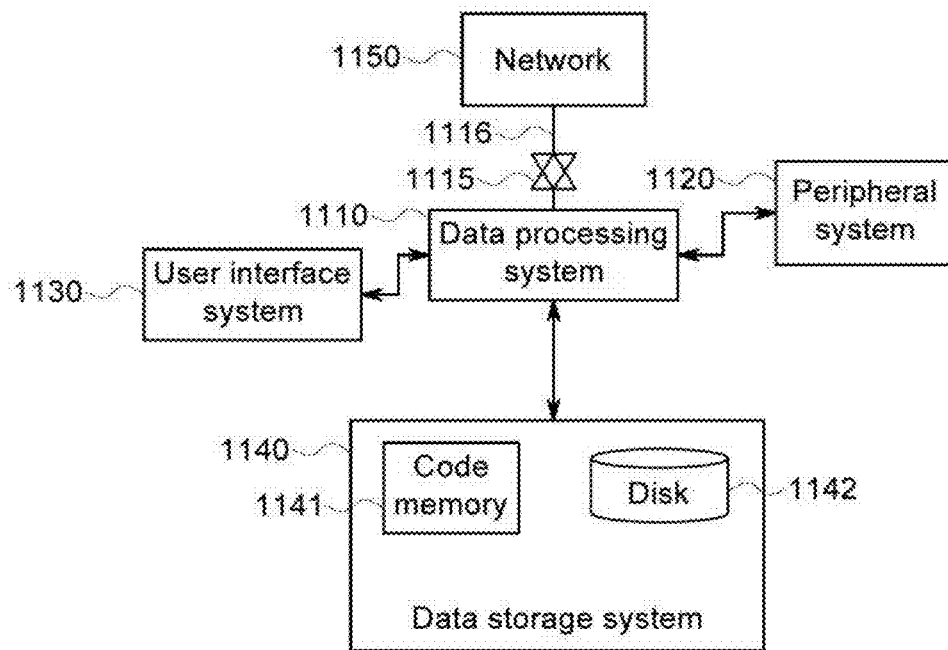
FIG. 3

FIG. 4
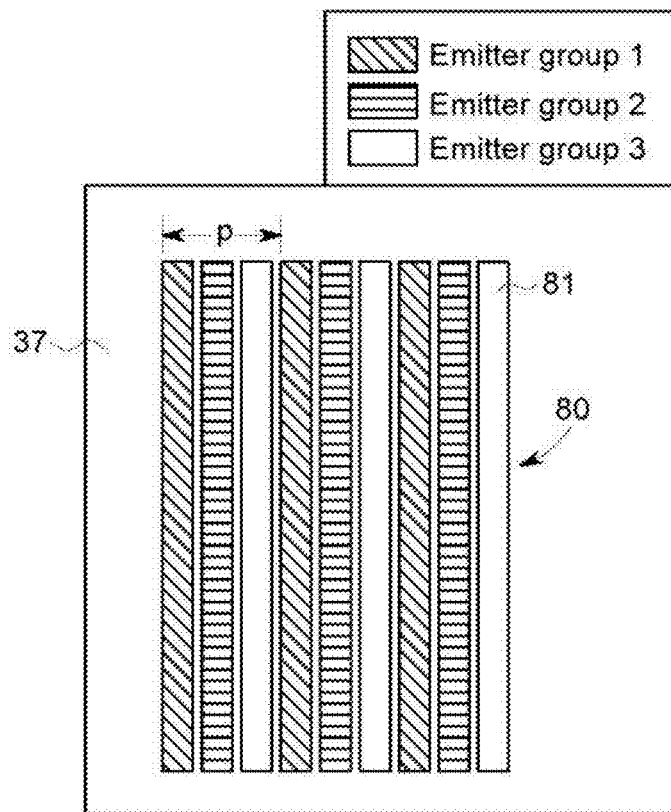
FIG. 5

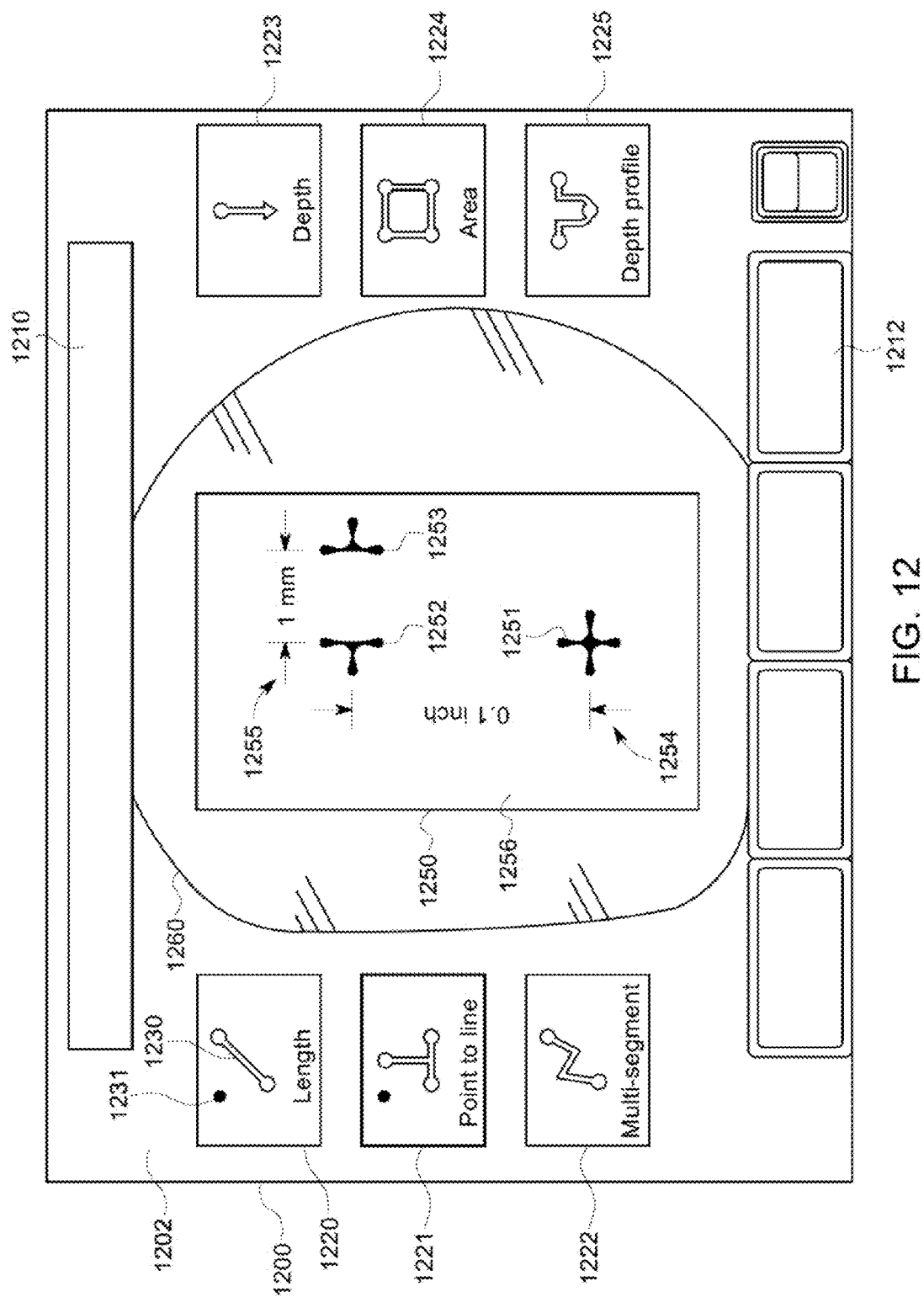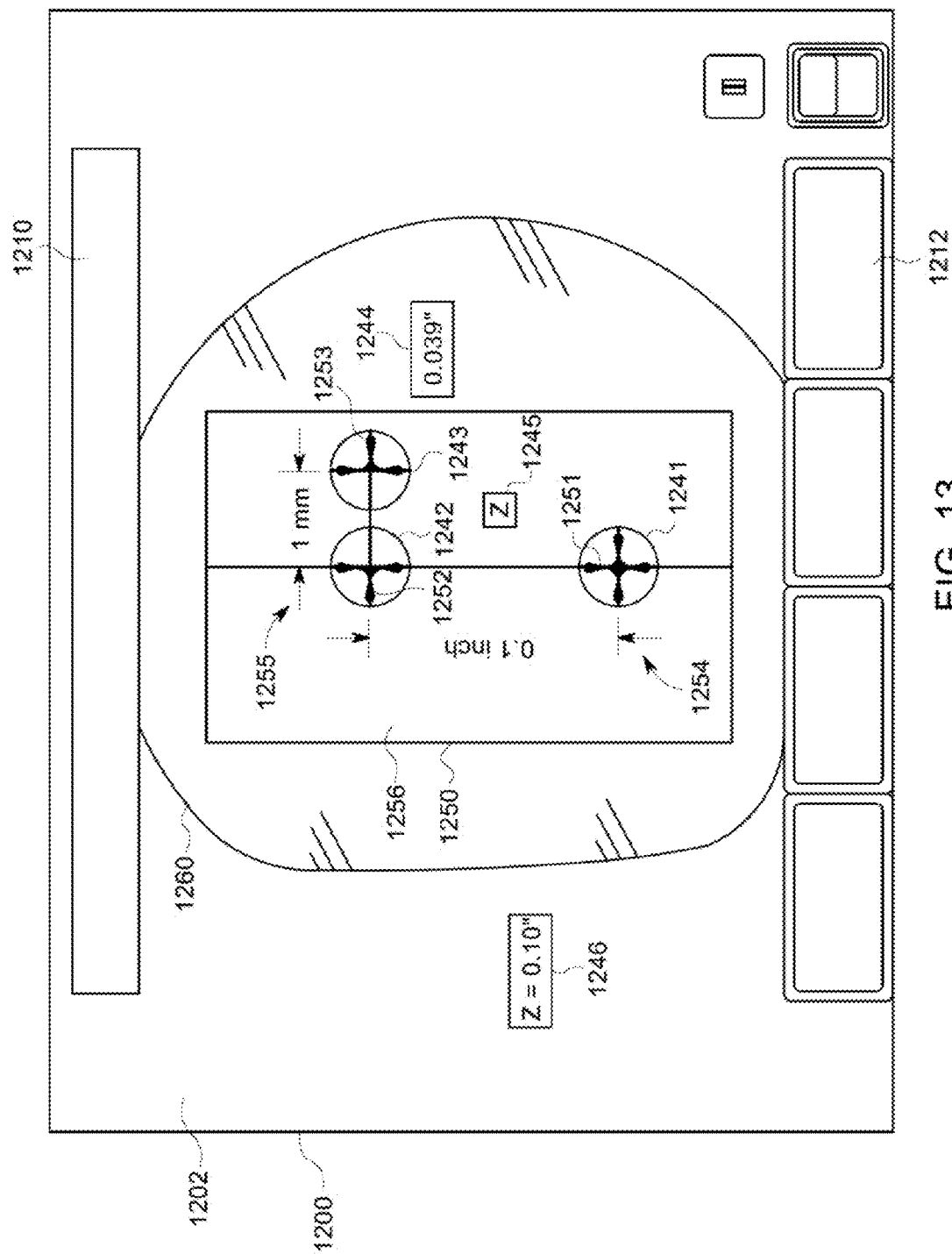FIG. 6



FIG. 7

FIG. 8A

FIG. 8B
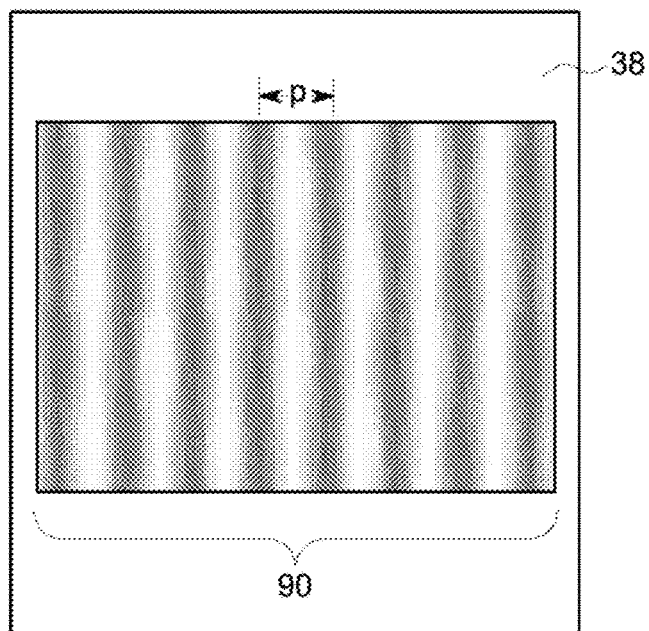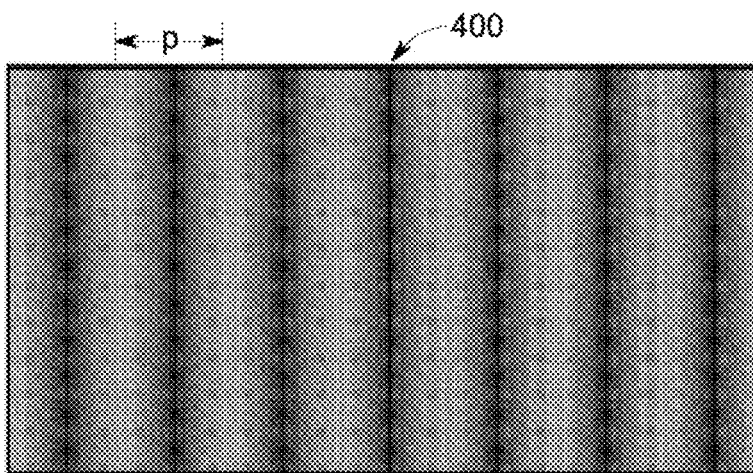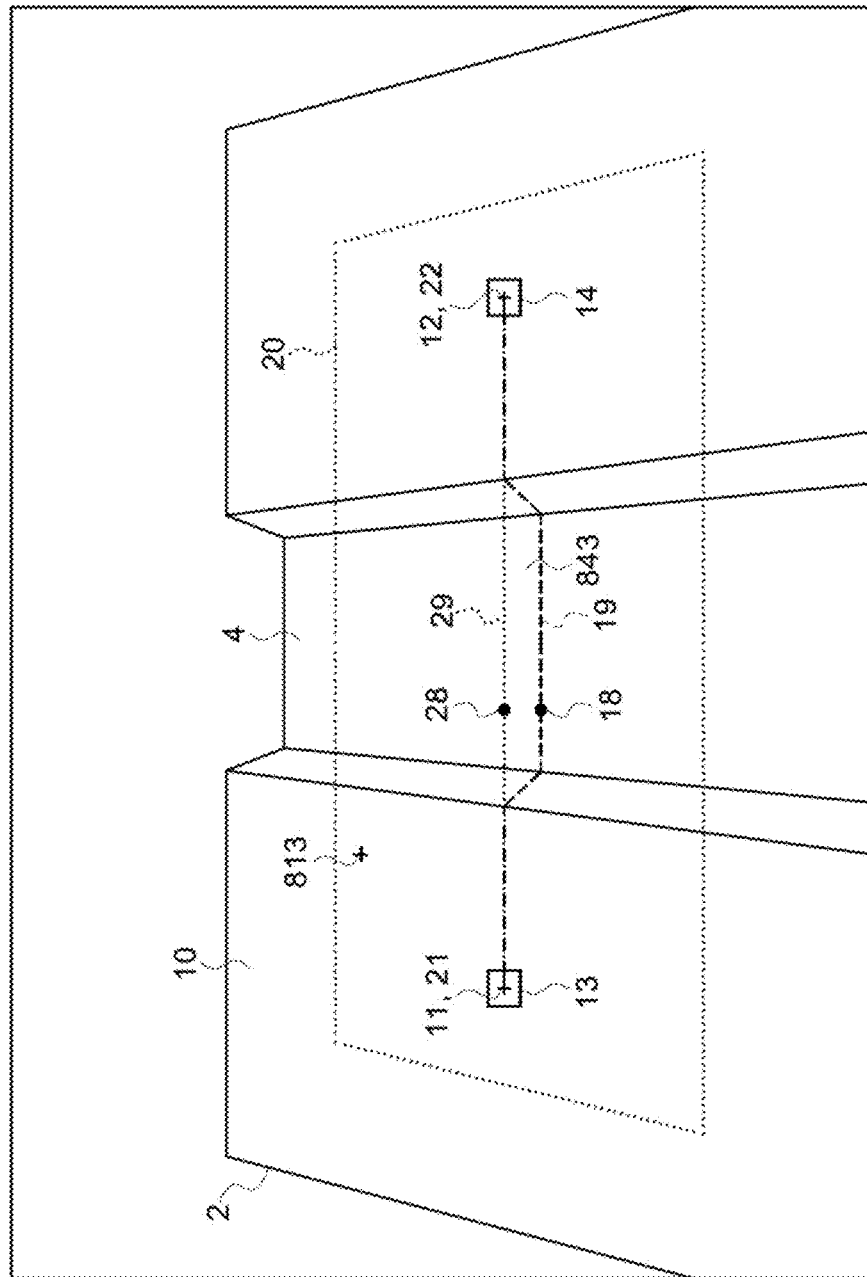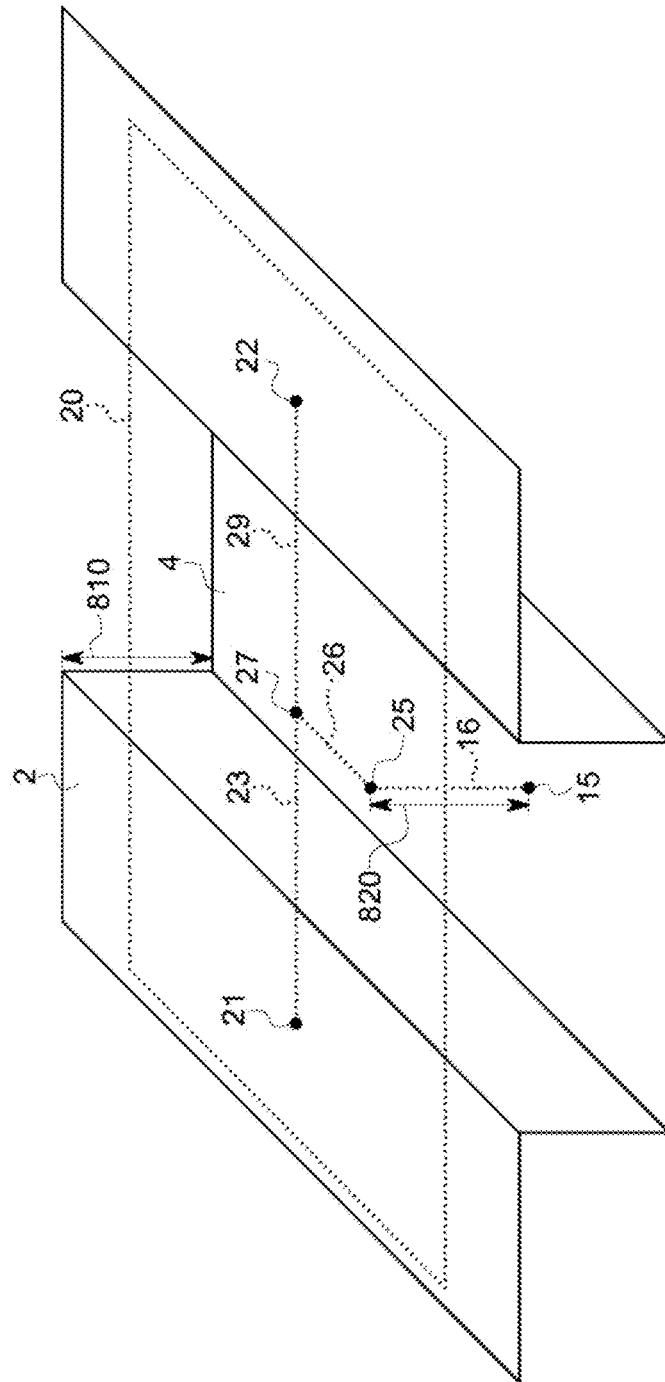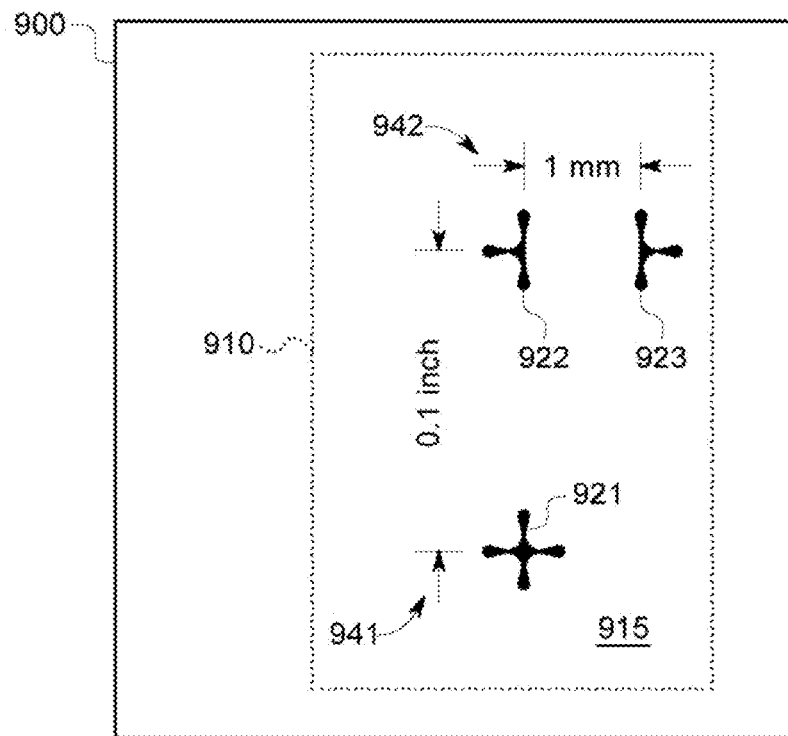
FIG. 9



FIG. 10

FIG. 11

FIG. 12
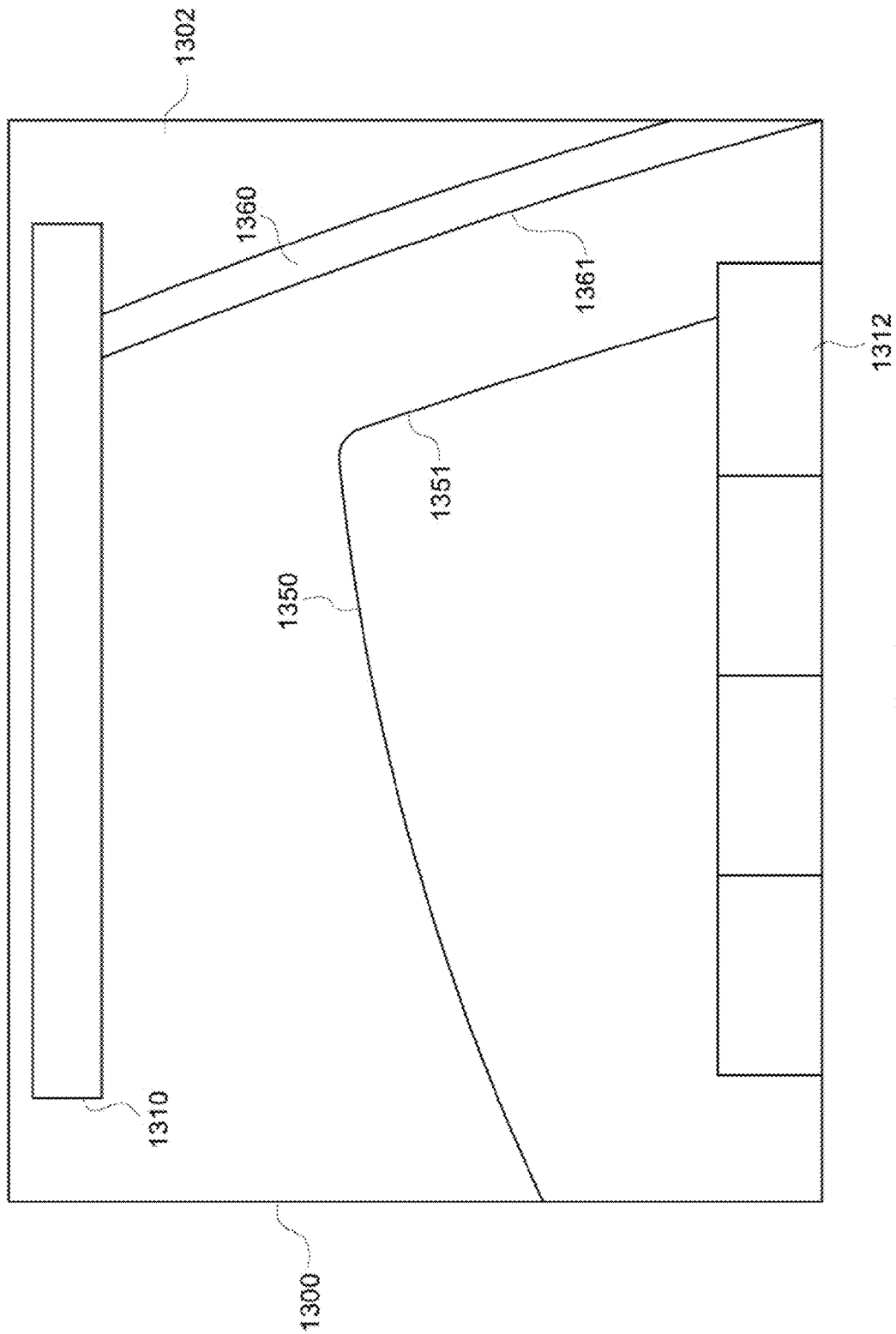
FIG. 13

FIG. 14

FIG. 15

FIG. 16

1400

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┌─────────────────┐
│    Capture       │
│    Image(s)      │────── 1410
└─────────────────┘
         │
         ▼
┌─────────────────┐
│    Display       │
│    image         │────── 1420
└─────────────────┘
         │
         ▼
┌─────────────────┐
│    Detect        │
│   measurable     │
│ object features  │────── 1430
└─────────────────┘
         │
         ▼
┌─────────────────┐
│    Display       │
│  measurement     │
│    types         │────── 1440
└─────────────────┘
         │
         ▼
┌─────────────────┐
│  Selection of    │
│  measurement     │
│    type          │────── 1450
└─────────────────┘
         │
         ▼
┌─────────────────┐
│  Automatically   │
│   position       │
│  measurement     │
│   markers        │────── 1460
└─────────────────┘
         │
         ▼
┌─────────────────┐
│    Display       │
│   computed       │
│   dimension      │────── 1470
└─────────────────┘
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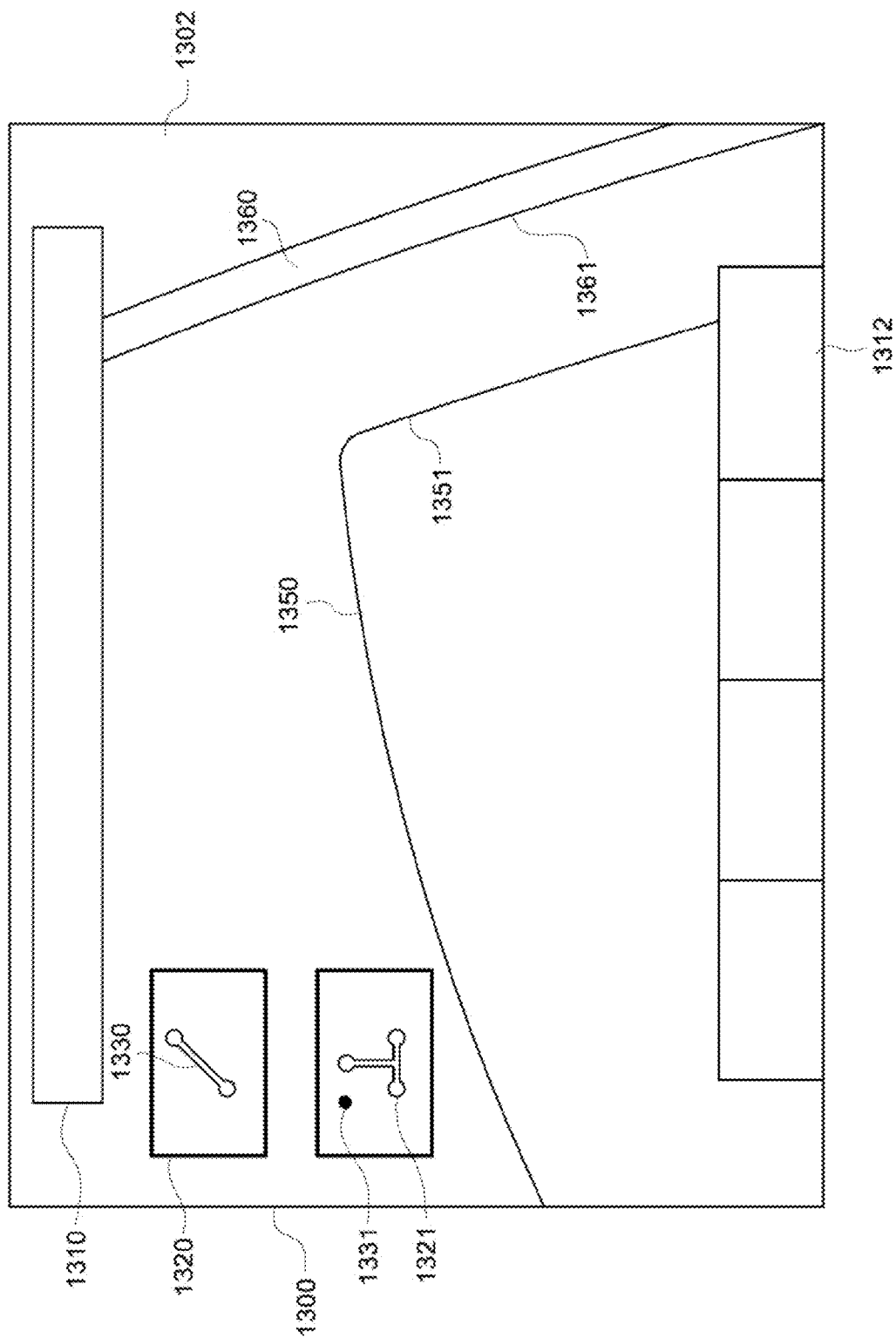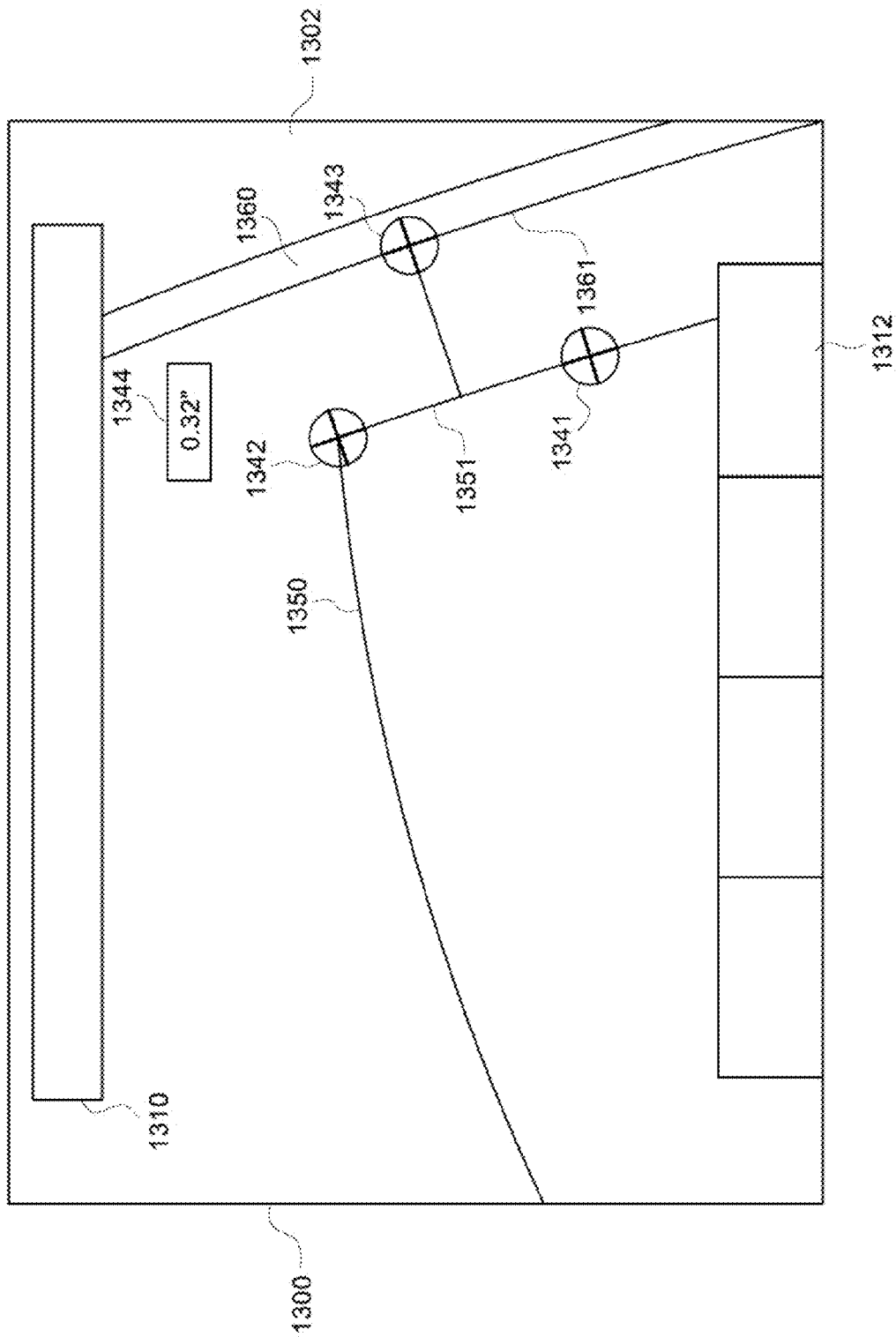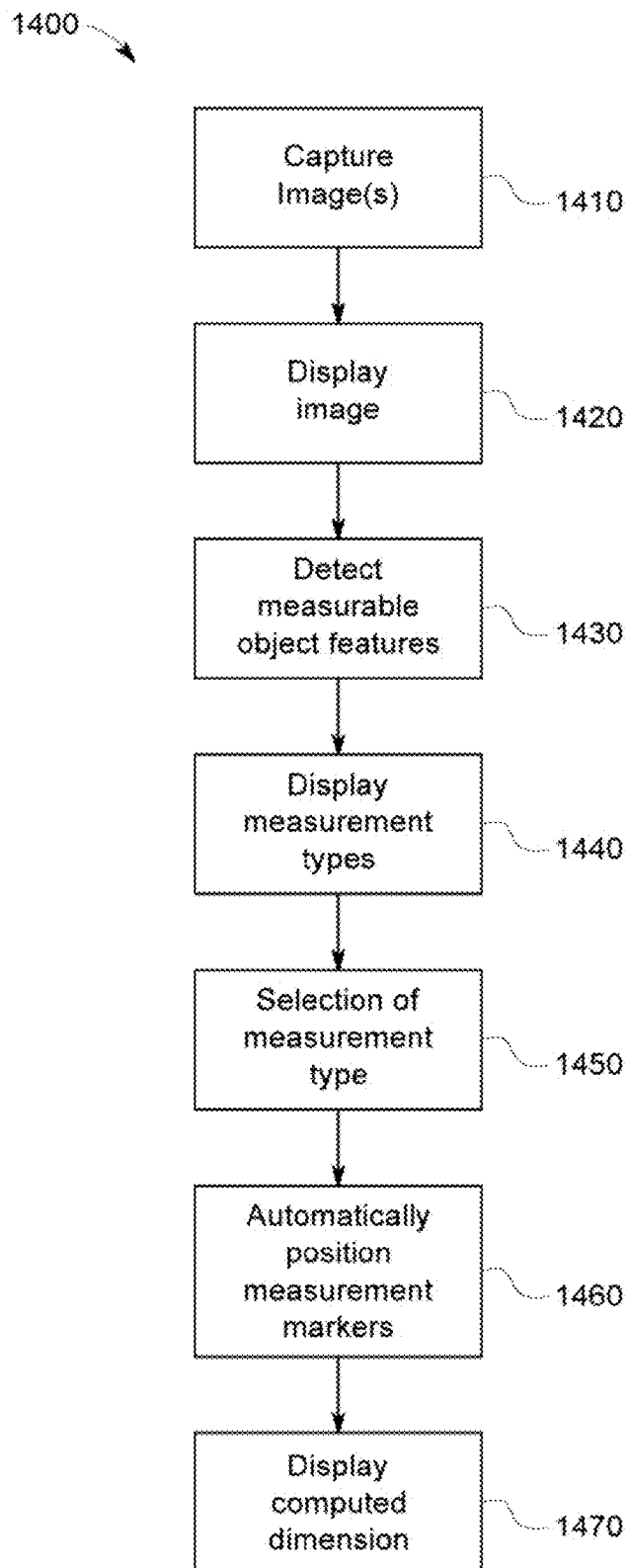
FIG. 17

# METHOD AND SYSTEM FOR DETECTING KNOWN MEASURABLE OBJECT FEATURES

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a Continuation-in-Part of, and claims priority to, U.S. patent application Ser. No. 13/892,794, filed May 13, 2013, and entitled AUTOMATED BORESCOPE MEASUREMENT TIP ACCURACY TEST, now U.S. Pat. No. 9,074,868, the entirety of which is incorporated herein by reference.

## BACKGROUND OF THE INVENTION

The subject matter disclosed herein relates to a method and system for detecting a known measurable object feature using a video inspection system.

Video inspection systems, such as video endoscopes or borescopes, can be used to inspect a surface of an object to identify and analyze anomalies or features (e.g., pits or dents) on the object that may have resulted from, e.g., damage, wear, corrosion, or improper installation. In many instances, the surface of the object is inaccessible and cannot be viewed without the use of the video inspection system. For example, a video inspection system can be used to inspect the surface of a blade of a turbine engine on an aircraft or power generation unit to identify any anomalies that may have formed on the surface to determine if any repair or further maintenance is required. In order to make that assessment, it is often necessary to obtain highly accurate-dimensional measurements of the surface and the anomaly to verify that the anomaly does not exceed or fall outside an operational limit or required specification for that object.

A video inspection system can be used to obtain and display a two-dimensional image of the surface of a viewed object showing the anomaly to determine the dimensions of an anomaly on the surface. This two-dimensional image of the surface can be used to generate three-dimensional data of the surface that provides the three-dimensional coordinates (e.g., (x, y, z)) of a plurality of points on the surface, including proximate to an anomaly. In some video inspection systems, the user can operate the video inspection system in a measurement mode to enter a measurement screen in which the user places cursors on the two-dimensional image to determine geometric dimensions of the anomaly. In many instances, the contour of a viewed feature is difficult to assess from the two-dimensional image, making highly accurate placement of the cursors proximate to the anomaly difficult as it is difficult for the user to visualize the measurement being performed in three-dimensional space. This process may not always result in the desired geometric dimension or measurement of the anomaly being correctly determined and can be time consuming.

The discussion above is merely provided for general background information and is not intended to be used as an aid in determining the scope of the claimed subject matter.

## BRIEF DESCRIPTION OF THE INVENTION

A method and system for detecting a known measurable object feature using a video inspection system is disclosed. The method and system displays an image of a viewed object and detects a known measurable object feature on the viewed object. The method and system then displays a set of available measurement types including a measurement type associated with the detected known measurable object feature and/or

automatically positions a plurality of measurement markers on the displayed image based on the measurement type associated with the detected known measurable object feature.

An advantage that may be realized in the practice of some disclosed embodiments of the method and system for automatically detecting a known measurable object feature using a video inspection system is the improved efficiency of the measuring process and the reduction in the level of skill required to perform the measurements.

In one embodiment, a method for automatically detecting a known measurable object feature on a viewed object using a video inspection system is disclosed. The method includes the steps of displaying on a display an image of the viewed object, detecting the known measurable object feature on the viewed object using a central processor unit, displaying on the display a set of available measurement types comprising a measurement type associated with the detected known measurable object feature using the central processor unit, receiving the selection of the measurement type associated with the detected known measurable object feature, automatically positioning a plurality of measurement markers on the image on the display using the central processor unit, wherein the positions of the plurality of measurement markers are based on the selected measurement type associated with the detected known measurable object feature, and displaying on the display a dimension of the measurable object feature computed by the central processor unit using the positions of the plurality of measurement markers.

In another embodiment, the method includes the steps of displaying on a display an image of the viewed object, detecting the known measurable object feature on the viewed object using a central processor unit, and automatically positioning a plurality of measurement markers on the image on the display using the central processor unit, wherein the positions of the plurality of measurement markers are based on a measurement type associated with the detected known measurable object feature, and displaying on the display a dimension of the measurable object computed by the central processor unit using the positions of the plurality of measurement markers.

In yet another embodiment, a system for automatically detecting a known measurable object feature on a viewed object using a video inspection system is disclosed. The system includes a display for displaying an image of the viewed object, and a central processor unit for detecting the known measurable object feature on the viewed object, displaying on the display a set of available measurement types comprising a measurement type associated with the detected known measurable object feature, receiving the selection of the measurement type associated with the detected known measurable object feature, automatically positioning a plurality of measurement markers on the image on the display, wherein the positions of the plurality of measurement markers are based on the selected measurement type associated with the detected known measurable object feature, and computing a dimension of the measurable object feature using the positions of the plurality of measurement markers.

This brief description of the invention is intended only to provide a brief overview of subject matter disclosed herein according to one or more illustrative embodiments, and does not serve as a guide to interpreting the claims or to define or limit the scope of the invention, which is defined only by the appended claims. This brief description is provided to introduce an illustrative selection of concepts in a simplified form that are further described below in the detailed description. This brief description is not intended to identify key features or essential features of the claimed subject matter, nor is it

intended to be used as an aid in determining the scope of the claimed subject matter. The claimed subject matter is not limited to implementations that solve any or all disadvantages noted in the background.

## BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the features of the invention can be understood, a detailed description of the invention may be had by reference to certain embodiments, some of which are illustrated in the accompanying drawings. It is to be noted, however, that the drawings illustrate only certain embodiments of this invention and are therefore not to be considered limiting of its scope, for the scope of the invention encompasses other equally effective embodiments. The drawings are not necessarily to scale, emphasis generally being placed upon illustrating the features of certain embodiments of the invention. In the drawings, like numerals are used to indicate like parts throughout the various views. Thus, for further understanding of the invention, reference can be made to the following detailed description, read in connection with the drawings in which:

FIG. 1 is a schematic diagram of an exemplary remote visual inspection system;

FIG. 2 is a perspective of components of a detachable tip for a remote visual inspection system according to an exemplary embodiment;

FIG. 3 is a flowchart illustrating exemplary ways of testing measurement accuracy of a remote visual inspection system;

FIG. 4 is a high-level diagram showing an exemplary data-processing system and related components;

FIG. 5 is top view of an exemplary light-emitting diode (LED) array on a light emitter module made using elongated die;

FIG. 6 is a top view of an exemplary intensity modulating element including a line grating;

FIG. 7 is an exemplary image of a structured light pattern created by passing light through an intensity modulating element;

FIG. 8A is a perspective of an exemplary test feature;

FIG. 8B is a perspective showing a cross-section of an exemplary test feature;

FIG. 9 is a plan view of an exemplary test feature;

FIG. 10 is a perspective of an exemplary test object;

FIG. 11 is an exemplary display of an exemplary image obtained by the video inspection system of a test object in an another exemplary embodiment of the invention;

FIG. 12 is the display of FIG. 11, now displaying a set of available measurement types;

FIG. 13 is the display of FIG. 12, now showing a plurality of measurement markers on the image on the display;

FIG. 14 is an exemplary display of an exemplary image obtained by the video inspection system of a turbine blade and shroud in an another exemplary embodiment of the invention;

FIG. 15 is the display of FIG. 14, now displaying a set of available measurement types;

FIG. 16 is the display of FIG. 15, now showing a plurality of measurement markers on the image on the display; and

FIG. 17 illustrates a flow diagram of an exemplary method for automatically detecting a known measurable object feature on a viewed object using the video inspection system.

## DETAILED DESCRIPTION OF THE INVENTION

In the following description, some embodiments will be described in terms that would ordinarily be implemented as software programs. Those skilled in the art will readily rec-

ognize that the equivalent of such software can also be constructed in hardware (hard-wired or programmable), firmware, or micro-code. Accordingly, embodiments of the present invention may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, or micro-code), or an embodiment combining software and hardware aspects. Software, hardware, and combinations can all generally be referred to herein as a "service," "circuit," "circuitry," "module," or "system." Various aspects can be embodied as systems, methods, or computer program products. Because data manipulation algorithms and systems are well known, the present description will be directed in particular to algorithms and systems forming part of, or cooperating more directly with, systems and methods described herein. Other aspects of such algorithms and systems, and hardware or software for producing and otherwise processing signals or data involved therewith, not specifically shown or described herein, are selected from such systems, algorithms, components, and elements known in the art. Given the systems and methods as described herein, software not specifically shown, suggested, or described herein that is useful for implementation of any aspect is conventional and within the ordinary skill in such arts.

FIG. 1 is a schematic diagram of an exemplary remote visual inspection system. Further details of this system are described in U.S. Publication No. 2011/0205552. Illustrated in FIG. 1, an exemplary borescope/endoscope probe or system 100 is shown. An insertion tube 40 comprises elongated portion 46 and detachable distal tip 42. Elongated portion 46 comprises a main long, flexible portion, a bending neck, and a camera head. Delineation line 41 shows where the camera head starts on elongated portion 46. The camera head of elongated portion 46 typically includes at least image sensor 112, electronics 113, and probe optics 115. Detachable distal tip 42 typically attaches to the camera head of elongated portion 46, mentioned above. Detachable distal tip 42 contains viewing optics 44 which are used in combination with probe optics 115 to guide and focus light received from the surface or object (not shown) onto image sensor 112. The viewing optics 44 may optionally include relay optics such as a lens or fiber optic system to remote the camera head away from the distal tip 42. Herein, the terms "imager" and "image sensor" are interchangeable.

Image sensor 112 may comprise, for example, a two-dimensional array of light-sensitive pixels that outputs a video signal in response to the light level sensed at each pixel. Image sensor 112 may comprise a charge-coupled device (CCD), complementary metal-oxide-semiconductor (CMOS) image sensor, or other devices of similar function. The video signal is buffered by electronics 113 and transferred to imager interface electronics 31 via signal line 114. Imager interface electronics 31 may include, for example, power supplies, a timing generator for generating image sensor clock signals, an analog front end for digitizing the image sensor video output signal, and a digital signal processor for processing the digitized image sensor video data into a more useful format for video processor 50.

Video processor 50 performs various functions not limited to image capture, image enhancement, graphical overly merging, and video format conversion and stores information relating to those functions in video memory 52. Video processor 50 may comprise field-programmable gate array (FPGA), digital signal processor (DSP), or other processing elements and provides information to and receives information from central processing unit (CPU) 56. The provided and received information may relate to commands, status information, video, still images, or graphical overlays. Video pro-

cessor 50 also outputs signals to various monitors such as computer monitor 122, video monitor 120, and integral display 121. Examples of components of or connected to video processor 50 are described below with reference to FIG. 4.

When connected, each of computer monitor 122, video monitor 120, or integral display 121 typically display images of the object or surface under inspection, menus, cursors, and measurement results. Computer monitor 122 is typically an external computer type monitor. Similarly, video monitor 120 typically includes an external video monitor. Integral display 121 is integrated and built into probe or system 100 and typically comprises a liquid crystal display (LCD).

CPU 56 can use both program memory 58 and non-volatile memory 60, which may include removable storage devices. CPU 56 may also use volatile memory such as RAM for program execution and temporary storage. A keypad 64 and joystick 62 convey user input to CPU 56 for such functions as menu selection, cursor movement, slider adjustment, and articulation control. Computer I/O interface 66 provides various computer interfaces to CPU 56 such as USB, FIREWIRE, Ethernet, audio I/O, and wireless transceivers. Additional user I/O devices such as a keyboard or mouse may be connected to computer I/O interface 66 to provide user control. CPU 56 generates graphical overlay data for display, provides recall functions and system control, and provides image, video, and audio storage. Examples of components of or connected to CPU 56 are described below with reference to FIG. 4. In various embodiments, CPU 56 is configured to perform phase-shift or shadow analysis and measurement processing.

Probe or system 100 further comprises contacts 36 that electrically couple elongated portion 46 to distal tip 42 through the camera head. Contacts 36 may be spring loaded and also provide electrical power from drive conductor 35 to light emitter module 37, which comprises a plurality of light emitters. Drive conductor 35 carries power from emitter drive 32 to the plurality of light emitters disposed in parallel on the distal end of insertion tube 40. Drive conductor 35 comprises one or more wires and may be incorporated with signal line 114 in a common outer jacket (not shown). Drive conductor 35 may also share conductors with signal line 114 or utilize the insertion tube 40 structure for carrying current. Emitter drive 32 includes, for example, an adjustable current source with a variable on time to compensate for light emitters with differing power capabilities and efficiencies. Emitter drive 32 also comprises brightness or fringe contrast determining function 39. Alternatively, video processor 50, discussed above, may include fringe contrast determining function 39.

The at least one light emitter module 37 on distal tip 42 can include a plurality of light emitters and optionally other electronics for control/sequencing of light emitters, sensing temperature, and storage/retrieval of calibration data. The at least one light emitter module 37 may include a heat sink made of a ceramic or metal, for example, to reduce the temperature rise of the plurality of light emitters. In various embodiments, light from a plurality of light emitters disposed on distal tip 42 is passed through at least one intensity modulating element 38 to alter the distribution of light and project at least one structured-light pattern on the surface suitable for phase-shift analysis. A fringe set comprises a structured-light pattern projected when one light emitter group of at least one of the plurality of light emitters is emitting light. Light from the plurality of light emitters is passed through the at least one intensity modulating element 38 to project a plurality of fringe sets onto the surface. In other embodiments, some light from one or more light emitter(s) is absorbed or reflected by an object that thereby casts a shadow of a known shape.

In embodiments using phase measurement, the probe operates in measurement mode when the at least one of the plurality of fringe sets is projected onto the surface. During measurement mode, light emitter module 37 is enabled and at least one digital image comprising a structured-light pattern on the surface is captured. Phase-shift analysis is may be performed directly on the at least one captured digital image. It may also be performed on data derived from the at least one captured digital image. For example, a luminance component derived from an YCrCb, RGB, or any other captured image format can be used. Thus, any reference to performing phase-shift analysis on an image made herein would include performing phase-shift analysis on the actual referenced image or on any data derived from the referenced image.

In embodiments using phase measurement, or in other embodiments, the probe operates in inspection mode when the at least one structured-light pattern is absent. During inspection mode, inspection light source 123 is enabled and outputs light from the distal end of insertion tube 40. The elements that produce and deliver light during inspection mode may collectively be referred to as an inspection light delivery system. In one embodiment, the inspection light delivery system comprises inspection light source 123, source fiber bundle 24, shutter mechanism 34, probe fiber bundle 125, and light passing element 43. In other embodiments, the inspection light delivery system may comprise very different elements such as, in the case of distally-located white LEDs, an LED drive circuit that can be disabled or provides an adjustable output current, wires for delivering power to the LEDs, the LEDs themselves, and a protective element to protect the LEDs. During measurement mode, the intensity of light output from the inspection light delivery system is automatically decreased to avoid reducing the contrast of the at least one structured-light pattern, for example.

Inspection light source 123 is typically a white light source, but may comprise any appropriate light source for a probe such as a mercury or metal halide arc lamp, halogen lamp, laser/phosphor system, or LED based light source which can be either proximally or distally located. When a fiber based light source is used, source fiber bundle 24 is included in probe or system 100. Source fiber bundle 24 comprises a non-coherent or semi-coherent fiber optic bundle and transmits light to shutter mechanism 34. Shutter mechanism 34 allows light output from the inspection light delivery system during inspection mode or regular inspection and blocks or otherwise inhibits light output from the inspection light delivery system during measurement mode or measurement pattern projection. Shutter mechanism 34 includes, for example, a solenoid or motor driven mechanical shutter or an electric light source disabler. The location of shutter mechanism 34 can vary based on its implementation. When shutter mechanism 34 allows light to pass, probe fiber bundle 125 delivers light to the surface or inspection site via light passing element 43. Probe fiber bundle 125 can include a non-coherent fiber optic bundle. Light passing element 43 can include a glass cane, formed fibers, or distribution control features such as lenses or a diffuser.

The previously discussed imager interface electronics 31, emitter drive 32, and shutter mechanism 34 are included in the probe electronics 48. Probe electronics 48 may be physically separated from a main control unit or CPU 56 to provide more local control over probe-related operations. Probe electronics 48 further comprise calibration memory 33. Calibration memory 33 stores information relating to the optical system of distal tip 42 or elongated portion 46 such as magnification data, optical distortion data, and pattern projection geometry data.

Microcontroller **30**, also included in probe electronics **48**, communicates with imager interface electronics **31** to determine and set gain and exposure settings; controls emitter drive **32** circuitry; stores and reads calibration data from the calibration memory **33**; controls shutter mechanism **34**; and communicates with CPU **56**. Examples of components of or connected to microcontroller **30** are discussed below with reference to FIG. **4**.

Referring back to distal tip **42**, the elements shown in distal tip **42** can alternatively be located on elongated portion **46**. These elements include viewing optics **44**, at least one light emitter module **37**, at least one intensity modulating element **38**, and light passing element **43**, discussed above. In addition, the at least one light emitter module **37** comprising a plurality of light emitters can be fixedly attached to insertion tube **40** while the at least one intensity-modulating element **38** is disposed on distal tip **42**. In such embodiments, precise and repeatable alignment between distal tip **42** and elongated portion **46** is required, permits realizing the advantage of permitting different fields of view while eliminating the need for contacts between elongated portion **46** and distal tip **42**.

Mentioned above, in phase-measurement embodiments, a structured-light pattern is created on the surface by passing light through at least one intensity-modulating element **38**, which alters the distribution of light. The structured-light pattern can comprise parallel light and dark lines comprising sinusoidal intensity profiles. Line patterns having square, trapezoidal, triangular, or other profiles may be projected on the surface as well when used with appropriate phase-shift analysis to determine phase of the pattern. The pattern may also comprise other than straight, parallel lines. For example, curved lines, wavy lines, zigzagging lines, or other such patterns may be used with appropriate analysis.

In one phase-measurement embodiment, the at least one intensity modulating element **38** comprises a line grating **90**, shown in FIG. **6**. In addition, the at least one light emitter module comprises a plurality of light emitters. Particularly, the at least one light emitter module comprises LEDs or an LED array.

In various phase-measurement embodiments, a fringe set comprises a structured-light pattern projected when one light emitter group of at least one of the plurality of light emitters is emitting light. The plurality of light emitters of light emitter module **37** are positioned such that the structured-light pattern projected when one group of at least one light emitter is emitting exhibits a spatial or phase-shift relative to the structured-light patterns projected when other groups of at least one light emitter are emitting. In other words, the structured-light pattern of one fringe set exhibits a spatial or phase-shift relative to the structured-light patterns of other fringe sets.

FIG. **2** is a perspective of components of a detachable tip **142** for a remote visual inspection system, e.g., a distal tip **42** (FIG. **1**), according to an exemplary embodiment. The tip **142** can be attached to insertion tube **40**, shown for orientation. The illustrated components of tip **142** can be enclosed in a housing that shields those components from dirt or other contaminants, mechanical damage, or harsh environments. The tip **142** can be used to perform phase measurements using structured-light patterns. Further details of tip **142** are described in the above-referenced U.S. Publication No. 2011/0205552.

Two light emitter modules **137a**, **137b** comprising a plurality of light emitters are positioned on each side of forward viewing optics **144**. The plurality of light emitters positioned on one side of viewing optics **144** comprises first light emitter module **137a**, and the plurality of light emitters positioned on the other side of viewing optics **144** comprises second light

emitter module **137b**. In addition, intensity modulating element **138** comprises two intensity modulating areas **138a** and **138b**, one intensity modulating area positioned on each side of forward viewing optics **144**. Light from first light emitter module **137a** is passed via path **170a** through intensity modulating area **138a**, which forms a first projection set, and light from second emitting module **137b** is passed via path **170b** through intensity modulating area **138b**, which forms a second projection set. Intensity modulating element **138** comprises line grating **190**, which alters the distribution of light and creates a structured-light pattern on the surface compatible with phase-shift analysis.

An image sensor (not shown) obtains a first image set and a second image set. The first image set comprises at least one image of a projection onto the surface of at least one of the plurality of fringe sets of the first projection set, and the second image set comprises at least one image of a projection onto the surface of at least one of the plurality of fringe sets of the second projection set.

First light emitter module **137a** associated with first intensity modulating area **138a** is positioned on one side of viewing optics **144**, and second light emitter module **137b** associated with second intensity modulating area **138b** is positioned on the other side of viewing optics **144** such that the at least one structured-light pattern reflected from the surface passes through viewing optics **144** to reach the image sensor (not shown).

The two light emitter modules **137a**, **137b** each comprise an elongated LED array **180**, which in turn comprises at least three light emitters. Alternatively, the two light emitter modules **137a**, **137b** may each comprise a plurality of light emitters, each of the plurality of light emitters comprising a series string of at least two LEDs. A light passing element (not shown), which delivers light from an inspection light source **123** (FIG. **1**) to the surface may also be included in distal tip **142**. Optional circuitry **150** located on distal tip **142** may control sequencing of the LEDs, select between single and multiple LEDs, sense temperature, and store/retrieve calibration data. The optional circuitry **150** can be managed by the CPU **56** or microcontroller **30** shown in FIG. **1**.

It will be understood that, while certain components have been shown as a single component (e.g., CPU **56**) in FIG. **1**, multiple separate components can be used to perform the functions of the CPU **56**.

In probe or system **100**, the first projection set comprises a plurality of fringe sets and the second projection set comprises a plurality of fringe sets. The plurality of light emitters are positioned such that the structured-light pattern of one fringe set of the first projection set projected from one light emitter group of the first light emitter module exhibits a phase-shift relative to the structured-light patterns of the other fringe sets of the first projection set projected from the other light emitter groups of the first light emitter module. Similarly, the structured-light pattern of one fringe set of the second projection set projected from one light emitter group of the second light emitter module exhibits a phase-shift relative to the structured-light patterns of the other fringe sets of the second projection set projected from the other light emitter groups of the second light emitter module.

The plurality of light emitters are positioned such that the structured-light pattern of one fringe set of the first projection set exhibits a spatial or phase-shift relative to the structured-light patterns of other fringe sets of the first projection set. Similarly, the structured-light pattern of one fringe set of the second projection set exhibits a spatial or phase-shift relative to the structured-light patterns of other fringe sets of the second projection set.

In one embodiment, the first light emitter module comprises three light emitter groups and the second light emitter module comprises three light emitter groups. Therefore, three fringe sets comprising the first projection set are produced from one side of viewing optics **144** and three fringe sets comprising the second projection set are produced from the other side of viewing optics **144**. Therefore, probe or system **100** can project a total of six fringe sets, three fringe sets from each side of the FOV. In order to improve brightness and contrast, light emitter modules **137a** and **137b** may include more than three LEDs along with a brightness determining function as described in detail above. Furthermore, the plurality of light emitters of light emitter modules **137a** and **137b** may each include a series string of at least two LEDs.

The accuracy of a system employing structured-light projection and phase-shift analysis is largely determined by its baseline spacing. In the case of a typical system wherein the absolute phase of a fringe set combined with its position in the FOV are used to determine absolute object distance, the baseline spacing is the distance between the projection origin and the camera field of view origin. In this embodiment, wherein the difference between the absolute phases of the two separate fringe sets is used to determine absolute object distance, the baseline spacing is the distance between light emitter modules **137a** and **137b**. Thus, accuracy is improved when the distance between the two light emitter modules **137a** and **137b** is larger than the distance between the viewing optics **144** and a single light emitter module **137**. As mechanical constraints in small-diameter probes make it difficult to substantially offset the viewing optics **144** from the center of the insertion tube **140**, the described embodiment employing two light emitter modules **137a** and **137b** can generally achieve a larger baseline spacing than could be achieved with a single light emitter module **137** in a forward-viewing system.

In addition, variability in the positioning of the distal tip **142** on the insertion tube causes the projections originating from the tip to shift relative to the FOV. If object distance is computed using absolute phase combined with position in the FOV, this shift causes error in the computed object distance. In this embodiment, such error is eliminated because the absolute phase difference is not affected by positioning of the tip on the insertion tube. In an alternative approach, the two LED arrays may also be located on one side of the viewing optics with a large grating where the first projection set is offset from the viewing optics by slightly more than the second projection set.

In some applications, it is desirable to obtain a view in a direction perpendicular to the probe axis, referred to as a side view. To obtain such a view, distal tip **142** may be replaced with a detachable side-viewing tip **242** (FIGS. **8** and **9**) comprising elements such as a side-view prism **210** through which the plurality of fringe sets reflected from the surface pass through viewing optics **244** to reach the image sensor (not shown).

FIG. **3** is a flowchart illustrating exemplary ways of testing measurement accuracy of a remote visual inspection (RVI) system. Briefly, a test object is placed in the field of view of the RVI system. The test object includes a test feature, e.g., a fiducial, having a known geometric characteristic. Images of the test object are captured and a geometric characteristic of the test feature is measured. The measured coordinates are compared to the known geometric characteristic to determine an accuracy value of the RVI system. The steps of this method can be automatically performed using a controller. Processing begins with step **310**.

In step **310**, attachment of a detachable measurement optical tip to a probe of the remote visual inspection system is detected. The probe can be, e.g., a straight-view or side-view tip. In various embodiments, the controller receives an interrupt on attachment of the detachable measurement optical tip. The controller can also periodically measure an electrical state of a conductor to detect attachment of the detachable measurement optical tip. The controller can detect attachment by monitoring or polling for either level-triggering signals or edge-triggering signals. After attachment of the detachable measurement optical tip is detected, step **310** is followed by step **320**. In various embodiments, the probe includes an image sensor (CCD or CMOS). In other embodiments, the detachable measurement optical tip includes an image sensor.

In various embodiments, detecting step **310** includes detecting a change in the resistance of a test circuit when the detachable measurement optical tip is attached. For example, a test voltage can be applied to a detection circuit and a voltage of a test point in the detection circuit can be measured. The detection circuit is configured so that the voltage of the test point is different when the detachable measurement optical tip is attached than when the detachable measurement optical tip is not attached. In an example, the test point is pulled up through a resistor to, e.g., +3.3 VDC when the optical tip is not attached, but when the optical tip is attached it shorts the test point to ground.

In various embodiments, detecting step **310** includes identifying step **315**. In step **315**, an identity of the attached measurement optical tip is determined. The measurement optical tip can transmit (via wire or wirelessly) identifying information to the controller, or the controller can analyze a resistance value or other electrical property at an interface between the tip and the probe. The identifying information can be used to select measurement calibration data associated with the attached measurement optical tip.

In step **320**, a user is prompted via a user-prompt device (e.g., computer monitor **122**, FIG. **1**) to perform testing of the measurement accuracy of the remote visual inspection system. For example, a "press OK to test" message can be displayed on a screen. Prompting step **320** can include waiting for a test-start indication from a user-input device, e.g., a touch on a touch sensor operatively arranged with respect to the user-prompt device. The touch sensor and user-prompt device can together compose a touchscreen. The user-input device can also be a button, e.g., on a keyboard, joystick, mouse, trackball, or RVI-system chassis or handset.

In some embodiments, step **320** includes guiding step **325**. In guiding step **325**, a motion image from an image sensor in the probe is presented on the screen. This can be a live video feed from the image sensor, or successively-presented still captures (e.g., one per second) from the image sensor. Additionally, whether simultaneously or not, a visual representation of an image from an image sensor in a desired orientation with respect to the test feature is presented on the screen. The desired orientation can include a desired relative position (translational displacement of the image sensor from the test feature), relative rotation, or both. The visual representation can be, e.g., an image or thumbnail of an image captured when an image sensor was in the desired orientation with respect to the test feature. The visual representation can be stored in a nonvolatile memory of the RVI system, e.g., data storage system **1140** (FIG. **4**).

In some embodiments using step **315**, guiding step **325** includes selecting the visual representation using the determined identity. In an example, referring to FIG. **10**, the test object is a test block **1010** having the test feature **1020** and two ports **1011**, **1077**: port **1011** to insert probes carrying straight-view tips, and port **1077** to insert probes carrying side-view tips. Dotted lines are shown for orientation. Line **1012** shows

an example of the orientation of a probe carrying a straight-view tip looking down on test feature **1020** (the term "down" is not limiting). As can be seen, a side-view tip in port **1077** can only view test feature **1020** from a limited range of orientations in the plane of test feature **1020** (rotation angle θ near 0°; how near can be selected based on the size of test target **120** and the field of view of the side-view tip). However, a straight-view tip in port **1011** can be turned freely to view test feature **1020** from any θ. Because of the characteristics of the particular tips used, it may be desirable for straight-view tips to view test feature **1020** at an angle θ≠0°. Moreover, some side-view tips flip the image vertically or horizontally. Therefore, the visual representation that will guide the user in turning a probe carrying a straight-view tip to the correct θ will be different from the visual representation that will guide the user in turning a probe carrying a side-view tip to the correct angle φ (rotation around an axis perpendicular to the θ axis; θ≡0° for a side-view tip in this example).

After prompting the user (step **320**), in step **330**, one or more images of the test feature on the test object are captured. This is done using the image sensor, which captures image data in a way appropriate for the attached measurement optical tip. For example, for stereo, shadow, or laser-dot tips, a single image can be captured. For phase measurement, multiple images can be captured. Step **330** is followed by step **340**.

In various embodiments, the detachable measurement optical tip is a structured-light-measurement optical tip having LEDs and gratings, e.g., as discussed below with reference to FIGS. **5-7**. On other embodiments, the detachable measurement optical tip is a stereo optical tip or a shadow optical tip. Shadow tips can include, e.g., a slit aperture through which light shines past an opaque line oriented parallel to the aperture. In embodiments using structured light, the detachable measurement optical tip can include a plurality of light-emitting-diodes (LEDs). The tip projects a structured light pattern onto an object in the field of view of the image sensor when the controller activates any of the LEDs. Stereo tips can include a beamsplitter, e.g., a prism, that directs light from two different viewing angles through a lens onto the image sensor. Therefore, the captured image includes two separate captures side by side, one capture from each of the viewing angles. Further examples of stereo tips are described in U.S. Pat. No. 7,170,677 to Bendall et al., incorporated herein by reference. Further examples of shadow tips are given in U.S. Pat. No. 4,980,763 to Lia, incorporated herein by reference.

In various embodiments, step **330** (or step **340**) includes analyzing at least one of the captured images to determine an orientation of the test feature with respect to the image sensor. For example, optical and mechanical tolerances, and variations in the way the user positions the tip with respect to the test feature, can cause the test feature to be located at different locations in a captured image frame each time a test sequence (starting with step **310**) is performed. The captured images themselves can be analyzed by identifying known features (e.g., orientation marks such as a letter "F") in the image and determining how those features are oriented with respect to the image sensor. This can permit determining whether a straight-view or side-view tip is being used. (In the example above, θ farther from 0 than the permitted range indicates a straight-view tip is in use.) It can also permit making use of captured images at angles different from a selected reference angle. This is useful because users may not always orient the tip at precisely a desired angle before images are captured.

When captured images are modified or otherwise processed, subsequent steps use the modified or processed images as the captured images.

In step **340**, coordinates of the test feature are determined using at least some of the captured images. This can be done using feature-extraction techniques such as thresholding, high-pass filtering or other edge-detection schemes, region extraction, dialating or eroding image data, or color extraction. Known colors or the known geometric characteristic of the test feature can be sought in the captured image(s) under consideration. Any number ≥1 of coordinates can be determined. The determined coordinates can be two-dimensional (2-D) or three-dimensional (3-D) coordinates. Coordinates can be expressed in Cartesian, polar, spherical, cylindrical, or homogeneous form. 2-D coordinates can be determined by, e.g., inverse projection mapping of the image data to an object plane. 3-D coordinates can be determined using existing techniques such as stereo, scanning systems, stereo triangulation, structured light methods such as phase shift analysis, phase shift moiré, and laser dot projection. Some of these techniques use calibration data that, among other things, includes optical characteristic data that is used to reduce errors in the three-dimensional coordinates that would otherwise be induced by optical distortions. With some techniques, the three-dimensional coordinates may be determined using one or more images captured in close time proximity that may include projected patterns and the like. Step **340** is followed by step **350**.

In some embodiments, step **350** is preceded by step **319**. In step **319**, calibration data corresponding to the attached measurement optical tip is automatically retrieved by the controller. The calibration data can include information relating sizes of images of objects to sizes of those objects, image coordinate frames to object coordinate frames, or brightness to distance. The calibration data can also include information about the tip, such as dimensions of gratings on a structured-light measurement tip. The calibration data can include information relating magnification to distance or information about optical distortion, structured-light projection geometry, or stereo perspective geometry.

In step **350**, a geometric characteristic of the test feature is measured using the determined coordinates of the test feature. In an example, the test feature includes two fiducials and the geometric characteristic is the distance between them. This distance can be measured by transforming the determined coordinates of the test feature in image space to physical dimensions (e.g., mm). The Euclidean distance between the physical coordinates can then be computed to determine the distance. In embodiments using step **319**, the measuring step is performed using the retrieved calibration data. Step **350** is followed by step **359** or step **360**.

The measured geometric characteristic can be a length, width, height, depth, or radius of the test feature. The measured geometric characteristic can also be a deviation of the test feature from a flat plane or other reference surface. The test feature can include a flat surface, a sphere or other raised three-dimensional (3-D) surface, or a slot, circular recess, or other recessed 3-D surface.

In various embodiments, the determined coordinates are three-dimensional (3-D) coordinates. The known geometric characteristic includes 3-D coordinates of a plurality of reference points, and the measured geometric characteristic includes a distance metric between at least some of the determined coordinates and the reference points. In various embodiments, step **350** includes measuring 3-D object coordinates of a plurality of points on the test feature. The 3-D object coordinates are then transformed via a coordinate

transform to a coordinate frame of the reference points. For example, structured-light, stereo, and shadow measurement optical tips can be used to capture images the controller can post-process into three-dimensional data. The 3-D object coordinates can be extracted from these data in a frame relative to the probe. They can then be transformed into a frame relative to the reference points, e.g., relative to the test feature.

In various embodiments, the distance metric is a quadratic mean (RMS), sum of squares, mean of squares, or average of respective distances between at least some of the determined coordinates and corresponding ones of the reference points. In an example, let the $i^{th}$ determined coordinate $(x_i, y_i, z_i)$ be represented as a vector $\vec{k}_i = [x_i\, y_i\, z_i]$, and the $i^{th}$ measured point likewise be $\vec{m}_i$, $i \in [1, n]$. The measured geometric characteristic $c_{mg}$ can be the root-mean-square (RMS) expression

$$c_{mg} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\left\|\vec{m}_i - \vec{k}_i\right\|^2\right)}.$$

This represents the overall difference between the known points and the measured points with a single value that can be tested in step **370**.

In another example, in step **350**, one or more value(s) representative of the measured geometric characteristic are provided. In this example, the known geometric characteristic includes one or more value(s) representative of the test feature. In this way, the value(s) representative of the test feature can be used instead of the measured data of the test feature itself. In an example, the test feature is a half-sphere, and two values representative thereof are the maximum widths of the half-sphere along two mutually-perpendicular axes (e.g., axes parallel to $\theta=0°$, $\theta=90°$ in FIG. **10**). These values should be equal within the manufacturing tolerances of the test feature. The extent to which the values differ beyond those tolerances is therefore an indication of the inaccuracy of the measurement. The two values can be compared to a known value of the width to determine inaccuracies in scale measurement (e.g., both values being about twice as large as the known value indicates a 2× magnification error) and to determine inaccuracies in measurements in one direction compared to measurements in another direction.

In another example, in 3-D, the known geometric characteristic is the flatness of the test feature. The test feature can be designed to be planar, within manufacturing tolerances, and the flatness can be the spacing between two parallel planes between which the test feature lies. The measured geometric characteristic is the corresponding spacing for the measured coordinates, and can be determined by, e.g., fitting a plane to the measured points and determining the distance along the normal to the plane between the two points farthest from the plane in the direction of that normal. The fitting can be done by least-squares or minimax optimization, or other mathematical optimization techniques.

In various embodiments, the known geometric characteristic is a plurality of regions and corresponding flatnesses. For example, the requirements for flatness of measured data of a known-flat surface can be more stringent at the center of the field of view than at an edge. Other known geometric characteristics described herein can also vary from center to edge, or from point to point or area to area of a captured image or of the test object itself. The known geometric characteristic can correspond to manufacturing tolerances of the test object.

In step **359**, an accuracy result is determined using the measured geometric characteristic and the known geometric characteristic. This can be done, e.g., as described below with reference to step **360**. The accuracy result is correlated with the measurement accuracy of the remote visual inspection system. In an example, determining-accuracy-result step **359** includes computing the accuracy result as a difference between the measured geometric characteristic from step **350** and the known geometric characteristic of the test feature. Step **359** can be followed by step **380** or step **360**.

In step **360**, in various embodiments, an accuracy value is determined based on the difference between the measured geometric characteristic and the known geometric characteristic of the test feature. This accuracy value is provided using the measurements taken in step **350**, which can themselves be computations based on captured image data. Continuing the fiducial-distance example above, the accuracy value can be the result of subtracting or dividing the known distance between the fiducials (e.g., 3 mm) and the measured distance between the fiducials (e.g., 3.14 mm), in either order. The accuracy value can be expressed in physical units, image-sensor units, percentages, standard deviations, or other appropriate measurement bases. Step **360** is followed by step **370**.

In step **370**, the determined accuracy value is compared to a predetermined acceptable accuracy value. For example, the determined accuracy value can be the ratio of measured characteristic to known characteristic and the predetermined acceptable accuracy value can be a percentage band, e.g., 100±20%. The determined accuracy value a can be the difference |measured-known|, as described above, and the predetermined acceptable accuracy value can be a difference threshold k such that a≤k (i.e., the computed difference(s) are less than the predetermined acceptable accuracy value) or 0≤a≤k. Continuing the distance-metric example above, the known geometric characteristic $c_{mg}$ takes into account the reference points and the measured points, so the $c_{mg}$ value does not need to be compared to a separate known value. Therefore, the comparison of determined accuracy value $c_{mg}$ to the predetermined acceptable accuracy value k can thus include determining whether $0 \leq c_{mg} \leq k$. A result of the comparison is provided as the accuracy result (discussed above with reference to step **359**). Step **370** is followed by step **380**.

In examples given above using value(s) representative of the geometric characteristics, step **360** includes computing difference(s) between the one or more value(s) representative of the measured geometric characteristic and the one or more value(s) of the known geometric characteristic. If more than one value is used, the difference can be a single difference computed from a plurality of (measured-value, known-value) pairs, or a plurality of differences between respective (measured-value, known-value) pairs. Step **370** can then include determining whether the computed difference(s) are within a selected percentage or dimensional amount of the predetermined acceptable accuracy value (e.g., a difference of 0±5%, or 0+5% --0%).

In step **380**, an indication is provided of the determined accuracy result, e.g., of the difference described above (step **359**) or of a result of the comparison described above (step **370**). For example, the indication can be a flag set or cleared in a memory operatively connected to the controller. The indication can also be a signal produced or not produced, or produced at a particular value or level, according to the result of the comparison. The indication can also be a visual, auditory, tactile, haptic, olfactory, or gustatory stimulus presented to the user, e.g., via a user-output device (e.g., computer monitor **122**, FIG. **1**). An example, using the user-prompt device as the user-output device, is a message displayed on

the screen that either "measurement is within specification" or "measurement is not within specification." In some embodiments, the indication is provided only on success (determined accuracy is within acceptable accuracy limits) or failure. Specifically, in some embodiments, the indication is presented only if comparing step 370 determines the measured accuracy value does not provide at least the predetermined acceptable accuracy. In some embodiments, step 370 or step 380 is followed by step 390.

In various embodiments, in step 390, after comparing step 370, the controller automatically activates at least one LED on the measurement optical tip at a selected drive current and captures an image using the image sensor. In some of these embodiments, capturing step 330 includes passing a selected test current through the at least one of the LEDs on the measurement optical tip. The selected test current is greater than the selected drive current. This can provide improved signal-to-noise ratio for images captured to test measurement accuracy without accelerating the burnout of the LEDs during normal operation.

In various examples, an identity of the attached measurement optical tip is determined, e.g., as discussed above with reference to step 315. The determined identity and the determined accuracy result are stored, e.g., in a database, file, or other data store. Detecting-attachment step 310, user-prompting step 320, image-capturing step 330, coordinate-determining step 340, characteristic-determining step 350, accuracy-result-determining step 359, identity-determining step 315, and the storing step are then repeated one or more times. This builds up a history in the data store of the tips that have been used, e.g., with a particular remote visual inspection system. The history can then be presented to a user. Trends can also be determined, and deviations from those trends presented to a user. This can permit, e.g., providing the user an indication that a tip may be approaching a point at which it will require maintenance. Using the data store, the characteristics of one or more tips can be tracked for diagnostic or prognostic purposes. In various aspects, the storing step (not shown) includes storing a determined serial number or other identity value of the tip, the date on which measurements were taken (e.g., in step 330), measured values such as the determined geometric characteristic, or the determined accuracy result (e.g., from step 359) or accuracy value (e.g., from step 360). The data store can be internal, e.g., on an internal Flash memory, or external, e.g., on a USB drive or SD card. Data can be imported to or exported from the data store, e.g., via a network or USB connection. Data from the same tip used on different borescopes can be combined to determine whether the tip or the borescope may need repair.

FIG. 5 is top view of an exemplary light-emitting diode (LED) array on a light emitter module made using elongated die. This array can be used, e.g., for performing phase measurements. Further details of this array are described in the above-referenced U.S. Publication No. 2011/0205552. Line grating 90 (FIG. 6) has a grating period p. Each light emitter 81 has a width less than ⅓ of the grating period p, and each light emitter 81 is lined up adjacent to each other with a center-to-center spacing of p/3. In this configuration, the line pattern projected when one light emitter 81 is emitting has a spatial or phase-shift of approximately ⅓ of the line period or 120° relative to the line pattern projected when the adjacent light emitter 81 is emitting. Exemplary emitting area dimensions for each light emitter 81 used with an 8 cycle/mm grating period p may be 35 μm×500 μm.

Alternatively, an effective phase-shift of 120° can be achieved with configurations in which the light emitter 81 spacing is other than ⅓ of the grating period. For example,

with a light emitter 81 spacing of ⅔ of the grating period, the light pattern projected when one light emitter 81 is emitting may have a phase-shift of 240° relative to the line pattern projected when the adjacent light emitter 81 is emitting. In this configuration, each light emitter 81 has width less than ⅔ of the grating period p, and each light emitter 81 is lined up adjacent to each other with a center-to-center spacing of 2p/3. Because multiple lines are projected each having a 0 to 360° phase range, the 240° phase-shift is equivalent to a 120° phase-shift. To generalize, by positioning light emitters 81 with a center-to-center spacing of approximately p/3 of the grating period where p is an integer that is not a multiple of 3, the light pattern projected when one light emitter 81 is emitting may have an effective phase-shift of approximately 120° relative to the line pattern projected when the adjacent light emitter 81 is emitting.

Multiple light emitters 81 are spaced apart by one grating period to create three separate light emitter groups. For clarification only, the light emitters 81 that comprise each of the three light emitter groups in FIG. 2 are indicated with a different pattern. LED array 80 comprises individual light emitters 81 of the same color. However, the color of light emitters 81 comprising one light emitter group can differ from the color of the light emitters 81 comprising other light emitter groups.

A plurality of light emitters 81 comprising each light emitter group are spaced apart along the axis perpendicular to the light emitters 81 and to the lines on the line grating by a distance approximately equal to an integer number of periods of the line grating. As a result, when the plurality of light emitters 81 comprising one light emitter group are simultaneously emitting light, the structured-light patterns produced by each of the multiple light emitters 81 sum together. This forms a brighter line pattern than would be generated by a single light emitter element. Increasing the light emitter width can increase brightness, but the line grating period must increase proportionally causing proportionally higher sensitivity to image noise. By using a plurality of narrow light emitters 81 as described, the pattern brightness can be increased without increasing the line grating period.

Referring to FIG. 5 and also to FIG. 1, emitter drive 32 comprises a brightness or fringe contrast determining function 39 to determine whether one light emitter 81 or multiple light emitters 81 should be enabled for each light emitter group. Because the light from the light emitters 81 is not collimated, the projected fringe sets expand as distance from the line grating increases. When multiple light emitters 81 of a light emitter group are simultaneously emitting, the individual fringe sets are offset by a constant distance (one grating period p as shown in the exemplary cases of FIGS. 5 and 6) rather than a constant phase, so their phases become more aligned as they expand. This results in progressively higher contrast as distance from the grating increases. Thus, when measuring a surface where more intensity is needed to achieve low image noise, multiple light emitters 81 from the same fringe set can be simultaneously turned on to provide more brightness at high contrast. However, at close distances, the sinusoidal intensities are not phase aligned and fringe set contrast decreases. Also, less intensity is needed at close distances; so when viewing a closer surface, one light emitter 81 can be turned on to achieve adequate intensity and high contrast.

Depending on the evaluation from brightness or fringe contrast determining function 39, one light emitter 81 or multiple light emitters 81 in each light emitter group are enabled for each fringe set. In one embodiment, drive conductor 35 comprises one or more drive wires (not shown) per

LED. Brightness or fringe contrast determining function **39** selectively transmits current through specific drive wires of drive conductor **35** to light an appropriate number of LEDs per fringe set.

Alternatively, brightness or fringe contrast determining function **39** can be located separately from emitter drive **32** and may comprise, for example, an analog detection circuit or video processor. With that assembly, one drive wire of drive conductor **35** connects emitter drive **32** to light emitter module **37**, and one or more control wires (not shown) controlled by brightness or fringe contrast determining function **39** are also connected to light emitter module **37**. A circuit (not shown) included on light emitter module **37** can selectively connect one or multiple LEDs to the drive wire in response to signals on the control wire(s).

Through the use of multiple light emitters **81** per fringe set and brightness or fringe contrast determining function **39**, LED array **80** offers adequate brightness and contrast during image capture and measurement. LED array **80** also offers consistent, uniform illumination, no speckling, and fast switching between fringe sets. Fast switching allows fringe set images to be captured in sequential frames, which reduces the likelihood of motion between image capture times. For at least these reasons, LED arrays are practical in this configuration. However, any light emitting source(s) offering the qualities mentioned above are sufficient for use in probe or system **100**. Other such light sources include, but are not limited to, organic LEDs, plasma elements, fiber coupled lasers, and laser arrays.

In another embodiment, LED array **80** is made using multiple series LEDs that comprise one light emitter **81** of a light emitter group. A light emitter **81** in this configuration may also be referred to as a string. Each light emitter or string **83** can comprise, e.g., 4 LEDs connected in series. Each light emitter or string **83** can be offset by approximately p/3 periods, where p is an integer that is not a multiple of 3. Each of the plurality of light emitters **81** may comprise a series string of at least two LEDs. For example, three strings can be used comprising four LEDs each, each string comprising its own light emitter group. However, a light emitter group may comprise a plurality of light emitters **81** or strings as well.

LED output is typically proportional to drive current. But, supplying high currents to distally-located LEDs using small wires is highly inefficient. By using multiple LEDs connected in series to comprise one light emitter or string **83**, less current is required to achieve a given combined LED output level. For example, series strings of 4 LEDs as shown in FIG. **4** can achieve the same output as single LEDs using $\frac{1}{4}^{th}$ of the current.

FIG. **6** is a top view of an exemplary intensity modulating element including a line grating. This element can be used for performing phase measurements. In at least one embodiment, the at least one intensity modulating element **38** comprises line grating **90**. In addition, the at least one light emitter module comprises a plurality of light emitters. The at least one light emitter module can include LEDs or an LED array.

A fringe set comprises a structured-light pattern projected when one light emitter group of at least one of the plurality of light emitters is emitting light. The plurality of light emitters of light emitter module **37** are positioned such that the structured-light pattern projected when one group of at least one light emitter is emitting exhibits a spatial or phase-shift relative to the structured-light patterns projected when other groups of at least one light emitter are emitting. In other words, the structured-light pattern of one fringe set exhibits a spatial or phase-shift relative to the structured-light patterns of other fringe sets.

FIG. **7** is an exemplary image of a structured light pattern created by passing light through an intensity modulating element. A structured-light pattern **400** is created on the surface of an object in the field of view of the image sensor, e.g., a test object, by passing light through at least one intensity-modulating element **38** (FIG. **1**), e.g., line grating **90** (FIG. **6**), which alters the distribution of light. The structured-light pattern **400** can comprise parallel light lines and dark lines comprising a sinusoidal intensity profile in the direction perpendicular to the lines (e.g., left to right across FIG. **7**). In this example, the centers of the light lines have high luminance values and the centers of the dark lines have low or no luminance. The dark lines of the structured light pattern **400** and the zero luminance values of the sinusoidal intensity profile can be formed by the columns of grating elements in line grating **90**. The grating period (p) is shown as the distance from the center of one light line to the center of the next light line. It will be understood that the grating period can be defined to start (and end) at various points along the sinusoidal intensity profile.

In one embodiment, the length of the grating period (p) (e.g., 0.125 mm (0.0049 in.)) of the first sinusoidal pattern on the intensity modulating element can be at least two times the width of the light emitters **81** (FIG. **5**) (e.g., 0.05 mm (0.00197 in.)) to provide effective contrast while providing a reasonable number of light and dark lines in the captured images. Reducing the length of the grating period (p) increases the number of light and dark lines and decreases the contrast of the image for a given light emitter **81** width. In one embodiment, the amplitude of the first sinusoidal pattern can be much smaller (e.g., at least five times smaller) than the length of the light emitters **81** so that the amplitude of the individual sinusoids (0.015 mm (0.00118 in.) in the projected pattern is relatively small, minimizing degradation of the sinusoidal intensity profile, but is large enough to achieve good contrast with manufacturable feature sizes (e.g., greater than 0.001 mm (0.0000394 in.)). Higher pattern contrast can provide lower noise than lower pattern contrast. In one embodiment, the intensity modulating elements can have approximately 15 columns and approximately 100 rows of grating elements.

In one embodiment, the substrate of the intensity modulating elements can be made of sapphire for durability. In one embodiment, grating elements are formed by photolithography on the intensity modulating elements using a coating that is highly absorptive of the wavelengths emitted by the light emitters **81** in order to minimize reflections. For example, if the light emitters **81** are emitting a red wavelength, a blue chrome that is highly absorptive (e.g., less than five percent reflectance at 750 nm) of the red wavelength can be used for the grating elements. It will be understood that other coatings and colors can be used to provide high absorption of the wavelengths emitted by the light emitters **81** (e.g., black anodized). In one embodiment, the grating elements can be applied only on the front side (i.e., side of the intensity modulating element facing the light emitters **81**), to avoid scratching or damage to the grating elements if located on the exposed back side of the intensity modulating element. In another embodiment, the grating elements can be applied on only the back side of the intensity modulating element, while in yet another embodiment, the grating elements can be applied to both the front side and the back side of the intensity modulating element. In one embodiment, an anti-reflective coating can be applied on top of the grating elements.

It will be understood that grating elements with non-sinusoidal patterns that approximate a sinusoidal pattern (e.g., a triangle pattern, a hexagon pattern) can also be used to pro-

duce a near sinusoidal intensity profile that can be compensated for during phase-shift analysis by the software.

FIG. 8A is a perspective, and FIG. 8B a perspective and cross-section, of an exemplary test feature. In this example, the test feature **4** is a groove in a test object **2**. The known geometric characteristic is distance **810**, which is the depth of the test feature **4**. The measured geometric characteristic is the distance **820** between point **15** and reference surface **20**. In an ideal (perfectly-manufactured) system, distances **810** and **820** are equal. Differences between distance **810** and distance **820** beyond manufacturing tolerances can indicate the condition of the measurement system. The location and orientation of point **15** and reference surface **20** are measured from the coordinates determined from the image data. In this example, the coordinates are three-dimensional.

First surface point **11** (e.g., a start surface point), second surface point **12** (e.g., a stop surface point), and third surface point **813** are automatically selected on the surface **10** of the test object **2**. Automatic selection can be part of step **350** (FIG. **3**). The automatic selection can be performed, e.g., by locating three fiducials in the image data and selecting coordinates (from step **340**, FIG. **3**) from each as the three points **11**, **12**, **813**. In one embodiment, the first surface point **11** can be selected on one side (e.g. the left side) of the test feature **4** to be measured, while the second surface point **12** can be selected on the other side (e.g., the right side) of the test feature **4** to be measured.

Continuing step **350** (FIG. **3**), in these embodiments reference surface **20** is determined based on the three-dimensional coordinates of the first surface point **11** and the second surface point **12**. In this example, the reference surface **20** is flat, while in other embodiments the reference surface **20** can be curved. Similarly, in one embodiment, the reference surface **20** can be in the form of a plane, while in other embodiments, the reference surface **20** can be in the form of a different shape (e.g., cylinder, sphere, etc.). The controller can perform a surface fitting of the three-dimensional coordinates of the first surface point **11**, the second surface point **12**, and the third surface point **813** to determine a reference surface equation (e.g., for a plane) having the following form:

$$k_{0RS}+k_{1RS}\cdot x_{iRS}+k_{2RS}\cdot y_{iRS}=z_{iRS} \tag{13}$$

where ($x_{iRS}$, $y_{iRS}$, $z_{iRS}$) are the coordinates of the surface points and $k_{0RS}$, $k_{1RS}$, and $k_{2RS}$ are coefficients obtained by a curve fitting of the three-dimensional coordinates. More than three points can be used. For example, the reference surface **20** can be based on, e.g., determined by surface-fitting to, the three-dimensional coordinates of a first plurality **13** of points on the surface **10** ($x_{iASP}$, $y_{iASP}$, $z_{iASP}$) and the three-dimensional coordinates of a second plurality **14** of points on the surface **10** ($x_{iBSP}$, $y_{iBSP}$, $z_{iBSP}$), and optionally at least one other point spaced apart from pluralities **13**, **14**.

It should be noted that a plurality of points (i.e., at least as many points as the number of k coefficients) are used to perform the fitting. The fitting finds the k coefficients that give the best fit to the points used (e.g., least squares approach). The k coefficients then define the plane or other reference surface **20** that approximates the three-dimensional points used. However, when you insert the x and y coordinates of the points used into the plane equation (13), the z results will generally not exactly match the z coordinates of the points due to noise and any deviation from a plane that may actually exist. Thus, the $x_{iRS}$ and $y_{iRS}$ can be any arbitrary values, and the resulting $z_{iRS}$ tells you the z of the defined plane at $x_{iRS}$, $y_{iRS}$. Accordingly, coordinates shown in these equations can

be for arbitrary points exactly on the defined surface, not necessarily the points used in the fitting to determine the k coefficients.

In various embodiments, the controller can determine the three-dimensional coordinates of a first reference surface point **21** on the reference surface **20** corresponding to the first surface point **11** on the surface **10** and a second reference surface point **22** on the reference surface **20** corresponding to the second reference surface point **12** on the surface **10**. In some circumstances, the three-dimensional coordinates of the first reference surface point **21** and the first surface point **11** can be the same. Similarly, the three-dimensional coordinates of the second reference surface point **22** and the second surface point **12** can be the same. However, in some circumstances, due to noise or small variations in the surface **10**, the first surface point **11** and the second surface point **12** do not fall exactly on the reference surface **20**, and therefore have different coordinates.

When determining points on the reference surface **20** that correspond to points on the surface **10**, it is convenient to apply the concept of line directions, which convey the relative slopes of lines in the x, y, and z planes, and can be used to establish perpendicular or parallel lines. For a given line passing through two three-dimensional coordinates (x0, y0, z0) and (x1, y1, z1), the line directions (dx, dy, dz) may be defined as:

$$dx=x1-x0 \tag{14}$$

$$dy=y1-y0 \tag{15}$$

$$dz=z1-z0 \tag{16}$$

Given a point on a line (x0, y0, z0) and the line's directions (dx, dy, dz), the line can be defined by:

$$\frac{(x-x0)}{dx} = \frac{(y-y0)}{dy} = \frac{(z-z0)}{dz} \tag{17}$$

Thus, given any one of an x, y, or z coordinate, the remaining two can be computed. Parallel lines have the same or linearly scaled line directions. Two lines having directions (dx0, dy0, dz0) and (dx1, dy1, dz1) are perpendicular if:

$$dx0\cdot dx1+dy0\cdot dy1+dz0\cdot dz1=0 \tag{18}$$

The directions for all lines normal to a reference plane defined using equation (13) are given by:

$$dx_{RSN}=-k_{1RS} \tag{19}$$

$$dy_{RSN}=-k_{2RS} \tag{20}$$

$$dz_{RSN}=1 \tag{21}$$

Based on equations (17) and (19) through (21), a line that is perpendicular to a reference surface **20** and passing through a surface point ($x_S$, $y_S$, $z_S$) can be defined as:

$$\frac{x-x_S}{-k_{1RS}} = \frac{y-y_S}{-k_{2RS}} = z-z_S \tag{22}$$

In one embodiment, the coordinates of a point on the reference surface **20** ($x_{iRS}$, $y_{iRS}$, $z_{iRS}$) that corresponds to a point on the surface **10** ($x_{iS}$, $y_{iS}$, $z_{iS}$) (e.g. three-dimensional coordinates a first reference surface point **21** on the reference surface **20** corresponding to the first surface point **11** on the surface **10**), can be determined by defining a line normal to the

reference plane having directions given in (19)-(21) and passing through $(x_{iS}, y_{iS}, z_{iS})$, and determining the coordinates of the intersection of that line with the reference plane. Thus, from equations (13) and (22):

$$z_{iRS} = \frac{(k_{1RS}^2 \cdot z_{iS} + k_{1RS} \cdot x_{iS} + k_{2RS}^2 \cdot z_{iS} + k_{2RS} \cdot y_{iS} + k_{ORS})}{(1 + k_{1RS}^2 + k_{2RS}^2)} \quad (23)$$

$$X_{iRS} = k_{1RS} \cdot (z_{iS} - z_{iRS}) + x_{iS} \quad (24)$$

$$y_{iRS} = k_{2RS} \cdot (z_{iS} - z_{iRS}) + y_{iS} \quad (25)$$

In one embodiment, these steps (equations (14) through (25)) can be used to determine the three-dimensional coordinates of a first reference surface point 21 $(x_{ARS}, y_{ARS}, z_{ARS})$ on the reference surface 20 corresponding to the first surface point 11 $(x_{AS}, y_{AS}, z_{AS})$ on the surface 10 and a second reference surface point 22 $(x_{BRS}, Y_{BRS}, z_{BRS})$ on the reference surface 20 corresponding to the second reference surface point 12 $(x_{BS}, y_{BS}, z_{BS})$ on the surface 10.

The controller can also determine the three-dimensional coordinates of a reference surface line 29 on the reference surface 20 from the first reference surface point 21 to the second reference surface point 22. There are several methods of determining the three-dimensional coordinates of a reference surface line 29. In one embodiment where the reference surface 20 is a plane, the three-dimensional coordinates of a reference surface line point 28 $(x_{RSL}, Y_{RSL}, z_{RSL})$ on the reference surface line 29 can be determined based on the three-dimensional coordinates of the first reference surface point 21 $(x_{ARS}, y_{ARS}, z_{ARS})$ and the second reference surface point 22 $(x_{BRS}, Y_{BRS}, z_{BRS})$ using the following relationship, where knowledge of one of the coordinates of the reference surface line point 28 $(x_{RSL}$ or $y_{RSL}$ or $z_{RSL})$ can be used to determine the other two:

$$\frac{x_{RSL} - x_{ARS}}{x_{BRS} - x_{ARS}} = \frac{y_{RSL} - y_{ARS}}{y_{BRS} - y_{ARS}} = \frac{z_{RSL} - z_{ARS}}{z_{BRS} - z_{ARS}} \quad (26)$$

Once the three-dimensional coordinates of the reference surface line points 28 $(x_{iRSL}, y_{iRSL}, z_{iRSL})$ on reference surface line 29 are determined, the controller can determine the three-dimensional coordinates of a surface contour 19 that is the projection of the reference surface line 29 onto the surface 10 of the test object 2, perpendicular to the reference surface 29. as shown, the surface contour 19 is not necessarily a straight line. Reference surface line 29 and surface contour 19 can extend between two of the points used to determine reference surface 20, or one of those points and another point on reference surface 20, or two other points on reference surface 20.

The controller can determine the distance of lines 26 from the reference surface line 29 to a plurality of reference surface

points 25 $(x_{iRS}, y_{iRS}, z_{iRS})$ on the reference surface 20 where surface-to-reference surface lines 16 extending from a plurality of surface points 15 $(x_{iS}, y_{iS}, z_{iS})$ on the surface 10 are perpendicular to the reference surface 20 and intersect the reference surface 20. The controller can automatically select the surface points 15 from the 3-D coordinates determined in step 340. For example, the test feature 4 can be identified by a fiducial, and the controller can select points within a predetermined distance of the fiducial as surface points 15. Alternatively, having determined reference surface 20, the controller can select as surface points 15 points that are more than a preselected distance from reference surface 20. The predetermined distance or the preselected distance can be included in the known geometric characteristic.

In one embodiment, for each of the plurality of surface points 15 $(x_{iS}, y_{iS}, z_{iS})$, equations (14) through (25) can be used to determine the three-dimensional coordinates of the reference surface points 25 $(x_{iRS}, y_{iRS}, z_{iRS})$ on the reference surface 20 corresponding to the surface points 15 $(x_{iS}, y_{iS}, z_{iS})$ on the surface 10 (e.g., for each, the reference surface point 25 where a surface-to-reference surface line 16 extending from the surface points 15 is perpendicular to the reference surface 20 and intersects the reference surface 20. The length of surface-to-reference-surface line 16 is distance 820, which is the measured geometric characteristic.

In one embodiment, once the three-dimensional coordinates of the reference surface points 25 $(x_{iRS}, y_{iRS}, z_{iRS})$ are determined, the controller can determine the distances of lines 26 extending in the reference surface 20 from the reference surface points 25 that are perpendicular to the reference surface line 29 and intersect the reference surface line 29 at reference surface line intersection points 27 $(x_{iRSLI}, y_{iRSLI}, z_{iRSLI})$. The three-dimensional coordinates of the reference surface line intersection points 27 can be determined by the following steps:

$$dx = x_{BRS} - x_{ARS} \quad (27)$$

$$dy = y_{BRS} - y_{ARS} \quad (28)$$

$$dz = z_{BRS} - z_{ARS} \quad (29)$$

$$z_{iRSLI} = \frac{(dx \cdot (dz \cdot (x_{iRS} - x_{BRS}) + dx \cdot z_{BRS}) + dy \cdot (dz \cdot (y_{iRS} - y_{BRS}) + dy \cdot z_{BRS}) + dz \cdot dz \cdot z_{iRS})}{(dx^2 + dy^2 + dz^2)} \quad (30)$$

$$y_{iRLSI} = \frac{dy \cdot (z_{iRLSI} - z_{BRS})}{dz + y_{BRS}} \quad (31)$$

$$x_{iRLSI} = \frac{dx \cdot (y_{iRLSI} - y_{BRS})}{dy + x_{BRS}} \quad (32)$$

In one embodiment, once the three-dimensional coordinates of the reference surface point intersection points 27 $(x_{iRSLI}, y_{iRSLI}, z_{iRSLI})$ corresponding to reference surface points 25 $(x_{iRS}, y_{iRS}, z_{iRS})$ are determined, the distance $(d_{26})$ of the line 26 between those points can be determined using the following:

$$d_{i26} = \sqrt{(x_{iRS} - x_{iRSLI})^2 + (y_{iRS} - y_{iRSLI})^2 + (z_{iRS} - z_{iRSLI})^2} \quad (33)$$

In one embodiment, this form of equation (33) can be used to determine the distance of a line between any two points on

the reference surface **20** whose coordinates (x, y, z) are known (e.g., the distance ($d_{16}$) of surface-to-reference surface line **16** from a surface point **15** to a reference surface point **25**, the distance ($d_{23}$) of the line **23** from a reference surface point intersection point **27** to the first reference surface point **21**, etc.).

The controller can determine the three-dimensional coordinates of a surface contour **19** on the surface **10** from the first reference surface point **21** to the second reference surface point **22** based on the surface points **15** whose perpendicular surface-to-reference surface lines **16** intersect the reference surface **20** on, or within a predetermined distance from, the reference surface line **29**. For example, if the distance of line **26** for a particular reference surface point **25** is greater than a threshold value, that is an indication that the surface point **15** ($x_S$, $y_S$, $z_S$) corresponding to that reference surface point **25** is far from the desired surface contour **19** that is the projection of the reference surface line **29** onto the surface **10** of the test object **2**, perpendicular to the reference surface **29**. On the other hand, if the distance of the line **26** for a particular reference surface point **25** is zero or less than a threshold value, that is an indication that the surface point **15** ($x_S$, $y_S$, $z_S$) is on or near the desired surface contour **19** that is the projection of the reference surface line **29** onto the surface **10** of the test object **2**, perpendicular to the reference surface **29**.

In one embodiment, the controller can select from the surface points **15** the set of surface contour points **18** ($x_{iSCL}$, $y_{iSCL}$, $z_{iSCL}$) whose corresponding reference surface points **25** have lines **26** with distances (($d_{26}$) given by equation (33)) that are less than a threshold value that can form the surface contour **19**. The controller can display an overlay on the image of the surface **10** indicating the location of the surface contour **19** on the surface.

The controller can determine the profile of the surface **10** of the test object **2** by determining the distance (e.g., the perpendicular distance) from the reference surface **20** to the surface contour **19** from the first reference surface point **21** ($x_{ARS}$, $y_{ARS}$, $z_{ARS}$) to the second reference surface point **22** ($x_{BRS}$, $y_{BRS}$, $z_{BRS}$). In one embodiment, the controller can automatically determine and display the area of a space **843** between the reference surface **20** and the surface contour **19**. The area can be determined by dividing the space **843** between the reference surface line **29** and the surface contour **19** into a plurality of polygons, such as rectangles, and summing the areas of those polygons. The controller can also automatically determine and display the distance from the reference surface **20** to the point on the surface contour **19** that is the furthest from the reference surface **20** to indicate the deepest or highest point in the test feature **4**. In one embodiment, the distance or area between the reference surface **20** and the surface contour **19** can be the distance or area between the reference surface line **29** and the surface contour **19**.

In one embodiment, the controller can display a graphical representation (not shown) of the profile of the surface **10** comprising a cross-section of the test object **2** at the surface contour **19** from the first reference surface point **21** to the second reference surface point **22**. The reference surface line **29** may not be shown in some embodiments. The graphical representation can also have a scale indicating the distance from the reference surface **20** to the surface contour **19**. This graphical representation can also be accompanied by a thumbnail of the image of the surface **10** of the test object **2**, also showing the reference surface line **29**.

Returning to FIG. **6**, in one embodiment, the graphical representation of the profile of the surface **10** can include a plot of the distances from the surface contour points **18** on the surface contour **19** to the reference surface **20**. In one embodi-

ment, the reference surface line **29** can be divided into equally spaced reference surface line points **28**, each corresponding to an x-value of the graphical representation. For each reference surface line point **28**, the distance from the surface contour **19** to the reference surface **20** can be determined by selecting the surface contour points **18** whose corresponding reference surface points **25** are within a certain threshold distance from the reference surface line point **28**, and determining the weighted average of the distance from those selected surface contour points **18** to the reference surface line point **28**. The weight assigned to the distance of each selected surface contour points **18** can be inversely proportional to the distance from the reference surface point **25** corresponding to that surface contour point **18** to the reference surface line point **28** (i.e., the smaller the distance, the greater the weight).

In various embodiments, the three-dimensional coordinates of at least three surface points **11**, **12**, **813** can be used to determine the reference surface **20** (e.g., a plane). In one embodiment and for improved accuracy, the controller can use the three-dimensional coordinates of all of the surface points on test object **2** to determine the reference surface **20**. Moreover, three-dimensional coordinates of at least three other surface points can be used to determine a second reference surface (e.g., a plane) for a second portion of test object **2**. Any number of planes or reference surfaces can be determined for a given test feature **4**, or for multiple test features on test object **2**. The known geometric characteristic can include data indicating how many reference surfaces to fit, where to position those surfaces with respect to fiducials or other features of the test object, and for using in computing which measured geometric characteristics.

FIG. **9** is a plan view of an exemplary test feature. Test feature **910** is a substantially planar surface of test object **900**, marked with or otherwise carrying at least two fiducials **921**, **922**. Fiducials **921**, **922** are arranged to be detectable by an image sensor in the probe. For example, if the image sensor is adapted to detect visible light, fiducials **921**, **922** are formed to reflect or absorb visible light differently than surround **915**. The controller can detect the fiducials in the image by image-processing techniques that differentiate fiducials **921**, **922**, **923** (e.g., black ink) from surround **915** (e.g., a white surface) as discussed above. The test feature can have a matte or glossy surface, or a combination. In an example, fiducials **921**, **922**, **923** and surround **915** have a matte finish.

In various embodiments, test feature **910** further includes third fiducial **923**, also formed to be detectable by an image sensor in the probe. Fiducials **921**, **922**, **923** can have the same shape, or different shapes, or two can have the same shape and one can have a different shape. The fiducials can be distinguishable from each other by the way they are arranged. In this example, they are arranged so that the three pairwise distances between them are different. The fiducials can also be distinguishable from each other by their shapes, colors, or other properties that are detectable by the image sensor or that can be determined by processing data from the image sensor. In this example, fiducial **921** is distinguishable from fiducials **922** and **923** by shape, and fiducials **922** and **923** are distinguishable from each other by their respective separations from fiducial **921**. Whether or not the fiducials are distinguishable, measuring step **350** (FIG. **3**) can include determining a first distance **931** between the first fiducial **921** and the second fiducial **922**, and a second distance **932** between the second fiducial **922** and the third fiducial **923**. If the fiducials are not distinguishable (e.g., are at the corners of an equilateral triangle and are identical), the choice of which fiducial is

first, second, and third can be made arbitrarily or using a random- or pseudorandom-number generator.

In this example, test feature **910** also includes labels **941**, **942** indicating to a human (or a computer with optical character recognition technology) the first distance between fiducials **921** and **922**, and the second distance between fiducials **922** and **923**, respectively. These labels provide a sense of scale, e.g., when the user is viewing a guide image (step **325**, FIG. **3**). In various embodiments, labels **941**, **942** can include machine-readable information, e.g., barcodes representing the serial number of test object **900**, the first and second distances, or other information.

As discussed above with respect to exemplary embodiment of FIG. **3**, the user is prompted to, and invokes, a test process to let the video inspection system **100** know that a test object having a test feature is the target of the inspection. Alternatively, FIG. **17** illustrates a flow diagram for an exemplary method **1400** for automatically detecting a known measurable object feature on a viewed object using the video inspection system **100**. In this embodiment, discussed below and with reference to FIGS. **11-17**, the detection of the known measurable object feature on a viewed object is performed without prior knowledge by the video inspection system **100** that the known measurable object feature is present in the image (e.g., the user did not select a particular feature or choose a particular process based on that feature). It will be understood that the steps described in the flow diagram of FIG. **17** can be performed in a different order that shown in the flow diagram and that not all steps are required for certain embodiments. As will be explained, the video inspection system **100** can automatically detect the known measurable object feature on the viewed object.

At step **1410** (FIG. **17**) and as shown in FIG. **11**, the user can use the video inspection system **100** (e.g., the imager **112**) to obtain or capture one or more images **1202** of a viewed object (e.g., test object **1250** positioned on surface **1260**). For example, for stereo, a single image can be captured. For phase measurement, multiple images can be captured. As shown in FIG. **11**, soft keys **1212** can be provided on the display **1200** to provide various functions to the user in obtaining images, including the selection of stereo or phase measurement to obtain the images **1202**. These soft keys **1212** can change depending on the particular mode that the video inspection system **100** is in. Text bar **1210** on display **1200** can provide prompts or the status of the process to the user (e.g., "Obtaining Image").

At step **1420** (FIG. **17**) and as shown in FIG. **11**, the video inspection system **100** can display the image **1202** of the viewed object **1250** on the display **1200**. This displayed image **1202** of the viewed object **1250** is based on the one or more images captured in step **1410** (FIG. **17**).

As shown in FIGS. **11-13**, the exemplary test object **1250** has several test features (e.g., fiducials **1251**, **1252**, and **1253**). Similar to the test object **900** shown in FIG. **9**, fiducials **1251** and **1252** are arranged to be detectable by an image sensor. For example, if the image sensor is adapted to detect visible light, fiducials **1251**, **1252**, **1253** are formed to reflect or absorb visible light differently than surround **1256**. The controller can detect the fiducials in the image by image-processing techniques that differentiate fiducials **1251**, **1252**, **1253** (e.g., black ink) from surround **1256** (e.g., a white surface) as discussed above. Fiducials **1251**, **1252**, **1253** can have the same shape, or different shapes, or two can have the same shape and one can have a different shape. The fiducials **1251**, **1252**, **1253** can be distinguishable from each other by the way they are arranged. In this example, they are arranged so that the three pairwise distances between them are different. The

fiducials **1251**, **1252**, **1253** can also be distinguishable from each other by their shapes, colors, or other properties that are detectable by the image sensor or that can be determined by processing data from the image sensor. In this example, fiducial **1251** is distinguishable from fiducials **1252** and **12533** by shape, and fiducials **1252** and **1253** are distinguishable from each other by their respective separations from fiducial **1251**. In this example, test object **1250** also includes labels **1254**, **1255** indicating to a human (or a computer with optical character recognition technology) the first distance between fiducials **1251** and **1252**, and the second distance between fiducials **1252** and **1253**, respectively. The labels **1254**, **1255** provide the actual distances between the fiducials for comparison to the computed distances allowing the accuracy of the system to be easily assessed using only the saved measurement image.

At step **1430** (FIG. **17**) and as shown in FIGS. **11** and **12**, the video inspection system **100** (e.g., the CPU **56**) can detect the known measurable object feature on the viewed object (e.g., test features (fiducials **1251**, **1252**, **1253**) on test object **1250**). This step **1430** may include the selection by the user of a soft key **1212** to set the video inspection system **100** in measurement mode. In one embodiment, the video inspection system **100** (e.g., the CPU **56**) can determine the three-dimensional coordinates (e.g., (x, y, z)) of a plurality of surface points on the test object **1250**. In one embodiment, the video inspection system **100** can generate three-dimensional data from the image **1202** in order to determine the three-dimensional coordinates. Several different existing techniques can be used to provide the three-dimensional coordinates (e.g., stereo, scanning systems, stereo triangulation, structured light methods such as phase shift analysis, phase shift moiré, laser dot projection, etc.).

Most such techniques comprise the use of calibration data, which, among other things, includes optical characteristic data that is used to reduce errors in the three-dimensional coordinates that would otherwise be induced by optical distortions. With some techniques, the three-dimensional coordinates may be determined using one or more images captured in close time proximity that may include projected patterns and the like. It is to be understood that references to three-dimensional coordinates determined using image **1202** may also comprise three-dimensional coordinates determined using one or a plurality of images captured in close time proximity, and that the image displayed to the user during the described operations may or may not actually be used in the determination of the three-dimensional coordinates.

Depending on the complexity of the viewed object, techniques such as pattern matching and/or use of three dimensional data can be used at step **1430** (FIG. **17**) to detect the known measurable object feature on the viewed object (e.g., test features (fiducials **1251**, **1252**, **1253**) on test object **1250**). In the embodiment shown in FIG. **11**, when the video inspection system **100** detects the known measurable object feature on the viewed object (e.g., test features (fiducials **1251**, **1252**, **1253**) on test object **1250**), it can display the text identifying the known measurable object feature in the text bar **1212** (e.g., "Test Block Detected").

At step **1440** (FIG. **17**) and as shown in FIG. **12**, the video inspection system **100** (e.g., the CPU **56**) can display on the display **1200** a set of available measurement types comprising measurement types (e.g., line **1220**, point-to-line **1221**) associated with the detected known measurable object feature (e.g., test features (fiducials **1251**, **1252**, **1253**) on test object **1250**). In one embodiment, the set of available measurement types further comprises measurement types (e.g., multi-seg-

ment **1222**, depth **1223**, area **1224**, depth profile **1225**) not associated with the detected known measurable object feature (e.g., test features (fiducials **1251**, **1252**, **1253**) on test object **1250**). In one embodiment, the measurement types are displayed with a graphic symbol **1230** of the measurement type and/or a textual description of the measurement type As can be seen in FIG. **12**, the measurement types (e.g., line **1220**, point-to-line **1221**) associated with the detected known measurable object feature (e.g., test features (fiducials **1251**, **1252**, **1253**) on test object **1250**) are displayed with a visual indicator **1231**, which is not present on the measurement types (e.g., multi-segment **1222**, depth **1223**, area **1224**, depth profile **1225**) not associated with the detected known measurable object feature. As shown in FIG. **12**, in one embodiment, the order of the displayed set of available measurement types can be changed based on the measurement types associated with the detected known measurable object feature (e.g., by listing first the measurement types (e.g., line **1220**, point-to-line **1221**) associated with the detected known measurable object feature).

At step **1450** (FIG. **17**) and as shown in FIG. **12**, the video inspection system **100** can receive the selection of the measurement type associated with the detected known measurable object feature (e.g., test features (fiducials **1251**, **1252**, **1253**) on test object **1250**) by the user. For example, the user can select the point-to-line measurement **1221**, which was associated with the detected known measurable object feature (e.g., test features (fiducials **1251**, **1252**, **1253**) on test object **1250**). In one embodiment, the user may select multiple measurement types.

At step **1460** (FIG. **17**) and as shown in FIG. **13**, the video inspection system **100** (e.g., the CPU **56**) can automatically position a plurality of measurement markers **1241**, **1242**, **1243** (e.g., cursors) on the image **1202** on the display **1200**, wherein the positions of the plurality of measurement markers **1241**, **1242**, **1243** are based on the selected measurement type (the point-to-line measurement **1221**)(FIG. **12**) associated with the detected known measurable object feature. For example, as shown in FIG. **13**, the measurement markers **1241**, **1242**, **1243** are automatically positioned on the fiducials **1251**, **1252**, **1253** on test object **1250** to conduct the point-to-line measurement **1221** (FIG. **12**). In one embodiment, the user may manually reposition the measurement markers **1241**, **1242**, **1243** if desired. In yet another embodiment, the user may add additional measurements while the automatically positioned measurement markers **1241**, **1242**, **1243** are displayed. In one embodiment, steps **1440** and **1450** can be bypassed and the video inspection system **100** (e.g., the CPU **56**) can automatically position a plurality of measurement markers once the video inspection system **100** (e.g., the CPU **56**) detects the known measurable object feature on the viewed object in step **1430**.

At step **1470** (FIG. **17**) and as shown in FIG. **13**, the video inspection system **100** can display on the display **1200** a dimension of the measurable object feature computed by the CPU **56** using the positions of the plurality of measurement markers **1241**, **1242**, **1243**. For example, the computed dimension **1244** between the second fiducial **1252** and the third fiducial **1253** (0.039 in. (1.0 mm)) and the computed dimension (z) **1245**, **1246** between the first fiducial **1251** and the second fiducial (**0.1** in (2.54 mm)) can be displayed.

While the exemplary known measurable object feature on the viewed object shown in FIGS. **11-13** was test features (fiducials **1251**, **1252**, **1253**) on test object **1250**, it will be understood that the method for automatically detecting a known measurable object feature on a viewed object using a video inspection system can be used to automatically detect

several different features, including, without limitation, a gap between a turbine blade tip and a shroud, a missing corner from a turbine blade tip, a curled turbine blade tip, a pit on the viewed object, a dent on the viewed object, a crack on the viewed object, a gap between two surfaces, a weld height, a weld angle, etc.

As shown in FIGS. **14-16**, the exemplary known measurable object feature is the gap between the tip **1351** of a turbine blade **1350** and the surface **1361** of the shroud **1360**. At step **1410** (FIG. **17**) and as shown in FIG. **14**, the user can use the video inspection system **100** (e.g., the imager **112**) to obtain or capture one or more images **1302** of a viewed object (e.g., the tip **1351** of the turbine blade **1350** and the surface **1361** of the shroud **1360**). As shown in FIG. **14**, soft keys **1312** can be provided on the display **1300** to provide various functions to the user in obtaining images, including the selection of stereo or phase measurement to obtain the images **1302**. These soft keys **1312** can change depending on the particular mode that the video inspection system **100** is in. Text bar **1310** on display **1300** can provide prompts or the status of the process to the user (e.g., "Obtaining Image").

At step **1420** (FIG. **17**) and as shown in FIG. **14**, the video inspection system **100** can display the image **1302** of the tip **1351** of a turbine blade **1350** and the surface **1361** of the shroud **1360** on the display **1300**. This displayed image **1302** of the viewed object is based on the one or more images captured in step **1410** (FIG. **17**).

At step **1430** (FIG. **17**) and as shown in FIGS. **14** and **15**, the video inspection system **100** (e.g., the CPU **56**) can detect the known measurable object feature on the viewed object (e.g., the gap between the tip **1351** of a turbine blade **1350** and the surface **1361** of the shroud **1360**). This step **1430** may include the selection by the user of a soft key **1312** to set the video inspection system **100** in measurement mode. As discussed above, in one embodiment, the video inspection system **100** (e.g., the CPU **56**) can determine the three-dimensional coordinates (e.g., (x, y, z)) of a plurality of surface points on the test object. In one embodiment, the video inspection system **100** can generate three-dimensional data from the image **1302** in order to determine the three-dimensional coordinates. Several different existing techniques can be used to provide the three-dimensional coordinates (e.g., stereo, scanning systems, stereo triangulation, structured light methods such as phase shift analysis, phase shift moiré, laser dot projection, etc.).

Depending on the complexity of the viewed object, techniques such as pattern matching and/or use of three dimensional data can be used at step **1430** (FIG. **17**) to detect the known measurable object feature on the viewed object (e.g., the gap between the tip **1351** of a turbine blade **1350** and the surface **1361** of the shroud **1360**). In one embodiment, the step **1430** of detecting the known measurable object feature on the viewed object using a central processor unit comprises detecting an edge of the viewed object (e.g., the edge of the turbine blade **1350**). In addition, the CPU **56** can identify the existence of two perpendicular surfaces (edge of the turbine blade **1350** and the surface **1361** of the shroud **1360**), with one surface extending past the other to identify the particular viewed object (e.g., the gap between the tip **1351** of a turbine blade **1350** and the surface **1361** of the shroud **1360**).

In the embodiment shown in FIG. **14**, when the video inspection system **100** detects the known measurable object feature on the viewed object (e.g., the gap between the tip **1351** of a turbine blade **1350** and the surface **1361** of the shroud **1360**), it can display the text identifying the known measurable object feature in the text bar **1312** (e.g., "Turbine Blade Tip To Shroud"). In one embodiment, a specific icon

for a measurement type can be displayed when the known measurable object feature is detected (e.g., an icon for the Turbine Blade Tip to Shroud measurement).

At step **1440** (FIG. **17**) and as shown in FIG. **15**, the video inspection system **100** (e.g., the CPU **56**) can display on the display **1300** a set of available measurement types comprising measurement types (e.g., point-to-line **1321**) associated with the detected known measurable object feature (e.g., the gap between the tip **1351** of a turbine blade **1350** and the surface **1361** of the shroud **1360**). In one embodiment, the set of available measurement types further comprises measurement types (e.g., line **1320**) not associated with the detected known measurable object feature (e.g., the gap between the tip **1351** of a turbine blade **1350** and the surface **1361** of the shroud **1360**). In one embodiment, the measurement types are displayed with a graphic symbol **1330** of the measurement type and/or a textual description of the measurement type. As can be seen in FIG. **15**, the measurement type (e.g., point-to-line **1321**) associated with the detected known measurable object feature is displayed with a visual indicator **1331**, which is not present on the measurement types (e.g., line **1320**) not associated with the detected known measurable object feature. As shown in FIG. **15**, in one embodiment, the order of the displayed set of available measurement types can be changed based on the measurement types associated with the detected known measurable object feature (e.g., by listing first the measurement type (e.g., point-to-line **1321**) associated with the detected known measurable object feature.

At step **1450** (FIG. **17**) and as shown in FIG. **15**, the video inspection system **100** can receive the selection of the measurement type associated with the detected known measurable object feature (e.g., the gap between the tip **1351** of a turbine blade **1350** and the surface **1361** of the shroud **1360**) by the user. For example, the user can select the point-to-line measurement **1321**, which was associated with the detected known measurable object feature (e.g., the gap between the tip **1351** of a turbine blade **1350** and the surface **1361** of the shroud **1360**). In one embodiment, the user may select multiple measurement types.

At step **1460** (FIG. **17**) and as shown in FIG. **16**, the video inspection system **100** (e.g., the CPU **56**) can automatically position a plurality of measurement markers **1341**, **1342**, **1343** (e.g., cursors) on the image **1302** on the display **1300**, wherein the positions of the plurality of measurement markers **1341**, **1342**, **1343** are based on the selected measurement type (the point-to-line measurement **1321**)(FIG. **15**) associated with the detected known measurable object feature. For example, as shown in FIG. **16**, the measurement markers **1341**, **1342**, **1343** are automatically positioned on the tip **1351** of the turbine blade **1350** and the surface **1361** of the shroud **1360** to conduct the point-to-line measurement **1321** (FIG. **15**). In one embodiment, the user may manually reposition the measurement markers **1341**, **1342**, **1343** if desired. In yet another embodiment, the user may add additional measurements while the automatically positioned measurement markers **1341**, **1342**, **1343** are displayed. In one embodiment, steps **1440** and **1450** can be bypassed and the video inspection system **100** (e.g., the CPU **56**) can automatically position a plurality of measurement markers once the video inspection system **100** (e.g., the CPU **56**) detects the known measurable object feature on the viewed object in step **1430**.

At step **1470** (FIG. **17**) and as shown in FIG. **16**, the video inspection system **100** can display on the display **1300** a dimension of the measurable object feature computed by the CPU **56** using the positions of the plurality of measurement markers **1341**, **1342**, **1343**. For example, the computed

dimension **1344** of the gap between the tip **1351** of the turbine blade **1350** and the surface **1361** of the shroud **1360** (0.32 in. (8.13 mm)) can be displayed.

An advantage that may be realized in the practice of some disclosed embodiments of the method and system for automatically detecting a known measurable object feature using a video inspection system is the improved efficiency of the measuring process and the reduction in the level of skill required to perform the measurements.

FIG. **4** is a high-level diagram showing the components of an exemplary data-processing system for analyzing data and performing other analyses described herein. The system includes a data processing system **1110**, a peripheral system **1120**, a user interface system **1130**, and a data storage system **1140**. The peripheral system **1120**, the user interface system **1130** and the data storage system **1140** are communicatively connected to the data processing system **1110**. Data processing system **1110** can be communicatively connected to network **1150**, e.g., the Internet or an X.25 network, as discussed below. A controller carrying out operations described above (e.g., in FIG. **3**) can include one or more of systems **1110**, **1120**, **1130**, or **1140**, and can connect to one or more network(s) **1150**. For example, microcontroller **30**, CPU **56**, or video processor(s) **50** (all FIG. **1**) can each include system **1110** and one or more of systems **1120**, **1130**, or **1140**.

The data processing system **1110** includes one or more data processor(s) that implement processes of various embodiments described herein. A "data processor" is a device for automatically operating on data and can include a central processing unit (CPU), a desktop computer, a laptop computer, a mainframe computer, a personal digital assistant, a digital camera, a cellular phone, a smartphone, or any other device for processing data, managing data, or handling data, whether implemented with electrical, magnetic, optical, biological components, or otherwise.

The phrase "communicatively connected" includes any type of connection, wired or wireless, between devices, data processors, or programs in which data can be communicated. Subsystems such as peripheral system **1120**, user interface system **1130**, and data storage system **1140** are shown separately from the data processing system **1110** but can be stored completely or partially within the data processing system **1110**.

The data storage system **1140** includes or is communicatively connected with one or more tangible non-transitory computer-readable storage medium(s) configured to store information, including the information needed to execute processes according to various embodiments. A "tangible non-transitory computer-readable storage medium" as used herein refers to any non-transitory device or article of manufacture that participates in storing instructions which may be provided to data processing system **1110** for execution. Such a non-transitory medium can be non-volatile or volatile. Examples of non-volatile media include floppy disks, flexible disks, or other portable computer diskettes, hard disks, magnetic tape or other magnetic media, Compact Discs and compact-disc read-only memory (CD-ROM), DVDs, BLU-RAY disks, HD-DVD disks, other optical storage media, Flash memories, read-only memories (ROM), and erasable programmable read-only memories (EPROM or EEPROM). Examples of volatile media include dynamic memory, such as registers and random access memories (RAM). Storage media can store data electronically, magnetically, optically, chemically, mechanically, or otherwise, and can include electronic, magnetic, optical, electromagnetic, infrared, or semiconductor components.

Embodiments of the present invention can take the form of a computer program product embodied in one or more tangible non-transitory computer readable medium(s) having computer readable program code embodied thereon. Such medium(s) can be manufactured as is conventional for such articles, e.g., by pressing a CD-ROM. The program embodied in the medium(s) includes computer program instructions that can direct data processing system **1110** to perform a particular series of operational steps when loaded, thereby implementing functions or acts specified herein.

In an example, data storage system **1140** includes code memory **1141**, e.g., a random-access memory, and disk **1142**, e.g., a tangible computer-readable storage device such as a hard drive or solid-state flash drive. Computer program instructions are read into code memory **1141** from disk **1142**, or a wireless, wired, optical fiber, or other connection. Data processing system **1110** then executes one or more sequences of the computer program instructions loaded into code memory **1141**, as a result performing process steps described herein. In this way, data processing system **1110** carries out a computer implemented process that provides for a technical effect of measuring geometric characteristics of the test feature and determining the physical condition of a remote visual inspection system. This condition (accurate or not) can then be reported to a user. In various embodiments, blocks of the flowchart illustrations or block diagrams herein, and combinations of those, can be implemented by computer program instructions.

Computer program code can be written in any combination of one or more programming languages, e.g., Java, Smalltalk, C++, C, or an appropriate assembly language. Program code to carry out methods described herein can execute entirely on a single data processing system **1110** or on multiple communicatively-connected data processing systems **1110**. For example, code can execute wholly or partly on a user's computer and wholly or partly on a remote computer, e.g., a server. The remote computer can be connected to the user's computer through network **1150**. The user's computer or the remote computer can be non-portable computers, such as conventional desktop personal computers (PCs), or can be portable computers such as tablets, cellular telephones, smartphones, or laptops.

The peripheral system **1120** can include one or more devices configured to provide digital content records or other data to the data processing system **1110**. For example, the peripheral system **1120** can include digital still cameras, digital video cameras, cellular phones, or other data processors. The data processing system **1110**, upon receipt of data from a device in the peripheral system **1120**, can store such data in the data storage system **1140**.

The user interface system **1130** can include a mouse, a keyboard, another computer (connected, e.g., via a network or a null-modem cable), a microphone and speech processor or other device(s) for receiving voice commands, a camera and image processor or other device(s) for receiving visual commands, e.g., gestures, or any device or combination of devices from which data is input to the data processing system **1110**. In this regard, although the peripheral system **1120** is shown separately from the user interface system **1130**, the peripheral system **1120** can be included as part of the user interface system **1130**.

The user interface system **1130** also can include a display device, a processor-accessible memory, or any device or combination of devices to which data is output by the data processing system **1110**. In this regard, if the user interface system **1130** includes a processor-accessible memory, such memory can be part of the data storage system **1140** even

though the user interface system **1130** and the data storage system **1140** are shown separately in FIG. **4**.

In various embodiments, data processing system **1110** includes communication interface **1115** that is coupled via network link **1116** to network **1150**. For example, communication interface **1115** can be an integrated services digital network (ISDN) card or a modem to provide a data communication connection to a corresponding type of telephone line. As another example, communication interface **1115** can be a network card to provide a data communication connection to a compatible local-area network (LAN), e.g., an Ethernet LAN, or wide-area network (WAN). Wireless links, e.g., WiFi or GSM, can also be used. Communication interface **1115** sends and receives electrical, electromagnetic or optical signals that carry digital data streams representing various types of information across network link **1116** to network **1150**. Network link **1116** can be connected to network **1150** via a switch, gateway, hub, router, or other networking device.

Network link **1116** can provide data communication through one or more networks to other data devices. For example, network link **1116** can provide a connection through a local network to a host computer or to data equipment operated by an Internet Service Provider (ISP).

Data processing system **1110** can send messages and receive data, including program code, through network **1150**, network link **1116** and communication interface **1115**. For example, a server can store requested code for an application program (e.g., a JAVA applet) on a tangible non-volatile computer-readable storage medium to which it is connected. The server can retrieve the code from the medium and transmit it through the Internet, thence a local ISP, thence a local network, thence communication interface **1115**. The received code can be executed by data processing system **1110** as it is received, or stored in data storage system **1140** for later execution.

In view of the foregoing, various embodiments of the invention image the test feature and process the images to determine whether a remote visual inspection system is operating within acceptable accuracy limits. A technical effect is to permit determining that a remote visual system should be used, or that it should not be used, or that it is in need of repair or recalibration.

The invention is inclusive of combinations of the aspects or embodiments described herein. References to "a particular aspect" or "embodiment" and the like refer to features that are present in at least one aspect of the invention. Separate references to "an aspect" or "particular aspects" or "embodiments" or the like do not necessarily refer to the same aspect or aspects; however, such aspects are not mutually exclusive, unless so indicated or as are readily apparent to one of skill in the art. The use of singular or plural in referring to "method" or "methods" and the like is not limiting. The word "or" is used in this disclosure in a non-exclusive sense, unless otherwise explicitly noted.

The invention has been described in detail with particular reference to certain preferred aspects thereof, but it will be understood that variations, combinations, and modifications can be effected by a person of ordinary skill in the art within the spirit and scope of the invention. Examples of variations, combinations, and modifications that are intended to be within the scope of the claims are those having structural elements that do not differ from the literal language of the claims and those including equivalent structural elements with insubstantial differences from the literal language of the claims.

What is claimed is:

1. A method for automatically detecting a known measurable object feature on a viewed object using a video inspection system, the method comprising the steps of:

displaying on a display an image of the viewed object;

detecting the known measurable object feature on the viewed object using a central processor unit;

displaying on the display a set of available measurement types comprising a measurement type associated with the detected known measurable object feature using the central processor unit;

receiving the selection of the measurement type associated with the detected known measurable object feature;

automatically positioning a plurality of measurement markers on the image on the display using the central processor unit, wherein the positions of the plurality of measurement markers are based on the selected measurement type associated with the detected known measurable object feature; and

displaying on the display a dimension of the measurable object feature computed by the central processor unit using the positions of the plurality of measurement markers.

2. The method of claim 1, wherein the set of available measurement types further comprises a measurement type not associated with the detected known measurable object feature.

3. The method of claim 1, wherein the measurement type associated with the detected known measurable object feature is displayed with a visual indicator.

4. The method of claim 1, wherein the known measurable object feature is a test feature on a test object.

5. The method of claim 1, wherein the known measurable object feature is one of a gap between a turbine blade tip and a shroud, a missing corner from a turbine blade tip, and a curled turbine blade tip.

6. The method of claim 1, wherein the known measurable object feature is one of a pit on the viewed object, a dent on the viewed object, and a crack on the viewed object.

7. The method of claim 1, wherein the known measurable object feature is one of a gap between two surfaces, a weld height, and a weld angle.

8. The method of claim 1, wherein the step of detecting the known measurable object feature on the viewed object using a central processor unit comprises

determining the three-dimensional coordinates of a plurality of points on the viewed object, and

detecting the known measurable object feature on the viewed object based on the three-dimensional coordinates.

9. The method of claim 8, wherein the step of detecting the known measurable object feature on the viewed object using a central processor unit comprises detecting an edge of the viewed object.

10. The method of claim 1, further comprising the step of obtaining one or more images of the viewed object using an imager, wherein the displayed image of the viewed object is based on the one or more images.

11. The method of claim 1, wherein an order of the displayed set of available measurement types is changed based on the measurement type associated with the detected known measurable object feature.

12. A method for automatically detecting a known measurable object feature on a viewed object using a video inspection system, the method comprising the steps of:

displaying on a display an image of the viewed object;

detecting the known measurable object feature on the viewed object using a central processor unit;

automatically positioning a plurality of measurement markers on the image on the display using the central processor unit, wherein the positions of the plurality of measurement markers are based on a measurement type associated with the detected known measurable object feature; and

displaying on the display a dimension of the measurable object computed by the central processor unit using the positions of the plurality of measurement markers.

13. The method of claim 12, further comprising the step of displaying on the display a set of available measurement types comprising the measurement type associated with the detected known measurable object feature using the central processor unit.

14. The method of claim 12, wherein the set of available measurement types further comprises a measurement type not associated with the detected known measurable object feature.

15. The method of claim 12, wherein the measurement type associated with the detected known measurable object feature is displayed with a visual indicator.

16. A system for automatically detecting a known measurable object feature on a viewed object using a video inspection system, the system comprising:

a display for displaying an image of the viewed object; and

a central processor unit for

detecting the known measurable object feature on the viewed object,

displaying on the display a set of available measurement types comprising a measurement type associated with the detected known measurable object feature,

receiving the selection of the measurement type associated with the detected known measurable object feature,

automatically positioning a plurality of measurement markers on the image on the display, wherein the positions of the plurality of measurement markers are based on the selected measurement type associated with the detected known measurable object feature, and

computing a dimension of the measurable object feature using the positions of the plurality of measurement markers.

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